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by

Captain Gerald P. Carr, USMC
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May, 1962

Aeronautical Engineering Report No. 608

PRINCETON UNIVERSITY

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SUMMARY

This report deals with an investigation of model tests to determine the most desirable winged GEM configuration to which the Curtiss-Wright Air Car can be modified. Tests on a modified C-W Air Car model showed that the addition of wings and nose and tail fairings had negligible effect on hover performance, but increased cruise performance and static longitudinal stability. Tests of a more general nature made on a rectangular model indicated that the addition of wings decreased hover performance and increased static roll stability.

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INTRODUCTION

Can the performance of Ground Effect Machines be improved by the addition of wings? Can an improvement in static stability be achieved with winged GEM's?

To answer these questions the study reported on herein was undertaken at the James Forrestal Research Center, Princeton University during the academic year 1961-62. The study involves modifying the Curtiss-Wright Air Car ACM 6-1, an annular jet type GEM shown in Fig. 1. Wings and aerodynamically faired nose and tail are to be added to improve cruise performance by generating aerodynamic lift. It is hoped that this lift will augment the propulsive power, or replace some of it so that power formerly used for propulsive lift might be used for horizontal thrust. The aerodynamic modifications are expected to give rise to a need for horizontal and vertical tail surfaces for pitch control and directional stability. Thus the modified C-W Air Car is to be a hybrid of GEM's and aircraft.

This report will include work done in hover model tests and wind tunnel tests to determine a desirable configuration for the modified C-W Air Car. The hover tests will be made to study the effect on lift augmentation and static roll stability brought about by the addition of wings of constant area, but of varying aspect ratio and of varying attachment height relative to the base of the machine. The hover tests will be made at several ground heights. The effect of wing dihedral will be briefly investigated.

Initial hover tests will be made with a very simple rectangular annular jet type model. The most desirable wing configuration will then be used for hover tests and wind tunnel tests of a scaled model of the modified C-W Air Car.

The wind tunnel tests are designed to analyze the static longitudinal stability, the lift, and the drag of the modified C-W Air Car model. Horizontal tail effects and wing location effects will be studied in some detail.

From the wind tunnel investigation the most desirable configuration will be chosen for consideration in modifying the actual C-W Air Car by the Forrestal Research Center. Future testing will then be done on the full-sized modified C-W Air Car. The results can be compared with results from testing the unmodified C-W Air Car as given in Report No. 8 of Project No. XE-709 by Curtiss-Wright Corporation and Princeton University, May 31, 1961.

The tests were conducted by Captains Gerald P. Carr and John J. Metzko, USMC, graduate students at Princeton University.

The authors sincerely appreciate the advice and guidance of Mr. Thomas E. Sweeney of the Aeronautical Engineering Department of Princeton University.

EQUIPMENT AND PROCEDURE

The initial static hover tests involved determining lift augmentation (L/mv_j) and roll stability ($\frac{dC_l}{d\emptyset}$) of a rectangular powered annular jet model with several simulated wing surfaces attached. Three wing planforms with a common wing area, but with aspect ratios of 2, 4, and 6, were used. The wing area for the modified C-W Air Car was arbitrarily chosen to be 100 ft^2. Expressed as a fraction of the base area of 108 ft^2 it is .925. This non-dimensional area was used to determine the wing planforms for the rectangular model assuming 50% of the model base area between the wings was effective wing area. The wings were flat wooden cutouts and were attached midway along the length of the model. The rectangular model planform had a 2:1 length-to width ratio. A drawing of the model is shown in Fig. 2.

The model was mounted inverted on three cantilever beams to which strain gages were attached. Strain readings from each beam were relayed through separate amplifiers and strain gage meters. These readings were then converted to forces by using strain-force calibration curves. The ground plane was a plexiglass disc adjustable in the vertical direction and in roll. Lift measurements were made by summing the three beam outputs. Moments for roll stability calculations were determined by multiplying the beam outputs by the appropriate moment arms.

The hover test rig and rectangular model are shown in Fig. 3. The model was tested first without wings, and then with the different wing planforms attached flush to the base of the model. Then the model was tested with the most desirable wing planform attached at discreet increments (δh) above the base. Tests were made at different heights above

the ground plane (h) to obtain lift augmentation data. The heights, δh and h, were non-dimensionalized by dividing by the overall base width (w).

At several selected ground heights the ground plane was adjusted to provide a succession of rolling attitudes from which static roll stability was determined. A final test was made of the rectangular model with wings attached at a $+5^{o}$ dihedral angle.

A simple technique for determining the nozzle thrust (mv_j) of the annular jet is introduced in Ref. 1. In this relationship m is the mass flow of air (slugs/sec.) and v_j is the jet velocity ($^{ft.}/sec.$). From the model geometry and a base pressure measurement the nozzle thrust can be closely calculated by

$$mv_j = \triangle p \; h \; C$$

where $\triangle p$ is air cushion pressure less atmospheric pressure, h is height above ground, and C is the base circumference of the model measured along the mid-points of the jet annulus. Since the same power was used for each test, mv_j remained constant. Several measurements of mv_j were made at low h/w's so that $\triangle p$ was not affected by vortices within the air cushion. Then the average mv_j of the several tests - in which the variation was very slight - was used as standard for the augmentation calculations. Lift augmentation is a non-dimensional parameter expressed by

$$A = {}^{L}/mv_j$$

where L is the lift measured by the beam support strain gages.

The final hover tests were made with a 1.25 inch: 1 foot scaled model of the modified C-W Air Car. The model was powered by two small direct current motors mounted in tandem. A picture of the modified C-W Air Car

model is shown in Fig. 4. The wings are of NACA 4412 section with an AR of 4, and were attached at a $\frac{\delta h}{w}$ of .129. A flexible skirt was attached in an attempt to match the full-scale configuration. This simulated skirt was used for the hover tests of the C-W Air Car model, but was not used on the model during the wind tunnel tests for reasons discussed in the analysis section.

The cruise testing was done in the Princeton University 4 ft. by 5 ft. wind tunnel. Forces and moments were measured by a mechanical balance. The model was mounted inverted on struts through the floor of the test section. Above the model was mounted a ground plane that could be adjusted vertically to vary $^{h}/w$. No boundary layer removal was provided for the ground plane.

A tunnel dynamic pressure (q) of 13 $^{lb.}/ft^{2}$. was used for all the cruise tests except one, for which a q of 6.5 $^{lb.}/ft.^{2}$ was used to determine fuselage effects.

The first wind tunnel test was made with the C-W Air Car model modified only with aerodynamically shaped nose and tail surfaces. Then a horizontal tail was added and tests made at tail incidences (i_t) of -2, +2, +6, and +10^{o}. An i_t of +2^{o} was chosen for the remaining tests, the next of which were with the addition of wings at two different horizontal positions. These positions measured from the model CG to the wing quarter chord, and expressed as fractions of model width ($^{l}/w$), were .105 forward and .455 aft of the CG respectively.

Fuselage effects were investigated by changing the nose shape, and by using the lower tunnel q mentioned above. Tests of the winged

model configuration were made at ground heights ($^h/w$) of .029, .058, and .117. The effects of model power were investigated by testing with power off, and with only the forward motor off and the inlet sealed so that no windmilling could take place. Final tests were made of the model in the freestream, i.e., with the ground plane removed, both at zero yaw and at 5^o of yaw. Both of these freestream tests were performed with and without model power.

Lift, drag, and pitching moment measurements were made for all wind tunnel tests. Side forces, yawing moments, and rolling moments were also measured for the yawed profile. The data were reduced, and are presented and discussed in the next section. Because several corrections are necessary for wind tunnel drag estimation, and since these corrections could not be applied with any degree of confidence, the drag data is of interest only to the extent of deducing drag trends.

RESULTS AND ANALYSIS

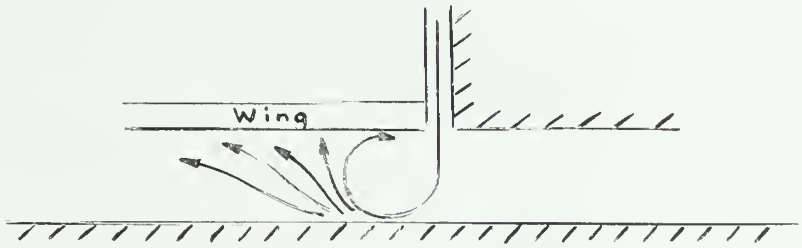
Once a winged GEM achieves enough speed so that sufficient aerodynamic lift is generated to cancel the added structural weight, wings should be a paying proposition. But until that "break-even" speed is reached, performance represented by lift augmentation ($^{L}/mv_j$) versus ground height ($^{h}/w$) must suffer. It was estimated that the modification to the C-W Air Car would make the machine about 5% heavier. If the added weight were taken as 160 lbs., and if a C_L of 1.0 is assumed, 100 $ft.^2$ of wing should generate that amount of lifting force at 25 mph.

Hover performance - rectangular model

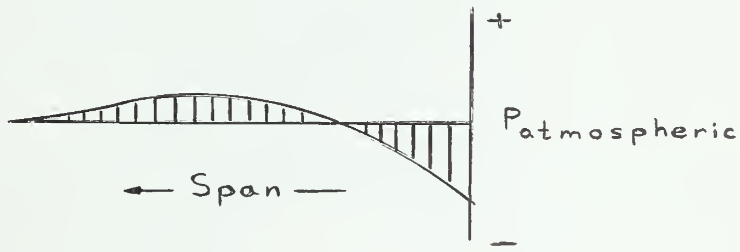
There was, however, a measurable effect on hover performance as the wing AR was varied while holding wing area constant. This effect is seen in Fig. 5 where lift augmentations have been calculated and plotted against ground heights up to $^{h}/w = 1.0$. The top curve is for the no-wing rectangular model while the lower curve resulted when AR 2 wings were added flush to the model base. Though not shown in Fig. 5, hover performances with AR 4 and AR 6 wings fall between those shown; the performance of the AR 6 wings most closely approaches the no-wing performance. The same results are shown in Fig. 6 for the four wing configurations, but only for a range of ground heights of more practical interest. The degradation of hover performance with decreasing AR, or with increasing chord, is quite apparent. An apt description for this phenomenon is "chord effect".

A seemingly reasonable explanation for the chord effect is that

vortex action induced by the outflowing jet results in negative pressures over areas adjacent to the annulus. A larger chord means a larger area on which the negative pressures act. Two-dimensional pressure distribution and smoke studies by Nixon and Sweeney in Ref. 2 indicate that a standing vortex is formed. In static hover tests of a modified C-W Air Car model, Mr. Dale Summers of Princeton University recorded substantiating pressure distributions along the wing span. His investigation indicated that along the span beyond the area of negative pressures there exists an area of positive pressure. This might well be an area influenced by stagnation pressures as illustrated below.



The pressure distribution would then be as shown in the following sketch.



The hover performance curves in Fig. 5 and 6 of this report indicate that the vorticity induced enough negative pressure over the wing root area to more than cancel the lift acting further along the span.

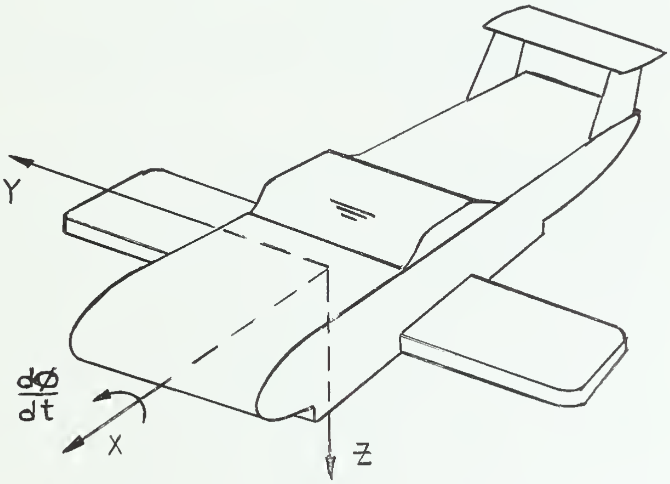
Ref. 1 shows that the loss of lift augmentation due to addition of

wings can be reduced by attaching them a distance δh above the machine base. Tests were made at four $\delta h/w$'s to investigate this effect. The results are shown in Fig. 7, which indicates that as $\delta h/w$ increases hover performance improves toward that of the no-wing configuration. It would appear that the reason for this is that the standing vortex gets larger and slower. Correspondingly the static pressure increases.

A simple smoke study of the air flow under the wings of the rectangular model revealed just such a vorticity and stagnation as suggested above.

Static roll stability - rectangular model

For stability studies in this report the conventional aircraft axis system is used. Roll stability is given by plots of rolling moment coefficient C_1 versus roll angle $\emptyset$.



Initial stability tests were made with wings attached flush to the model base. The results are shown in Fig. 8, 9, and 10. At the lower $^h/w$'s, Fig. 8 shows the model to be unstable without wings. At $^h/w$ = .060, the addition of wings of all three AR's made $\frac{dC_1}{d\emptyset}$ go negative.

As $^h/w$ was increased to .119, however, the stabilizing influence of the wings was markedly decreased. In fact the model was unstable in roll, or at best neutrally stable, up to 3° of roll with AR 2 and AR 4 wings attached. As $^h/w$ was increased still further, Fig. 9 and 10 show that the presence of wings of all AR's had no effect on the roll stability.

Because only the derivative $\frac{dC_l}{d\phi}$ is of interest in the roll stability tests, no corrections for tares in the measuring apparatus were made. This explains why most of the moment coefficients are not zero at $\phi = 0^o$.

To determine the effect on roll stability of attaching the wings at a distance above the model base, the AR 4 wings were attached at $^{\delta h}/w$'s of .030, .060, and .119. This was of interest since it was shown that hover performance improved as $^{\delta h}/w$ increased. The roll stability at $^h/w$ = .060 is shown in Fig. 11. Also at $^h/w$ = .119 a comparison of a no-wing configured model is made with configurations with $^{\delta h}/w$'s of 0 and .030. At both ground heights it is seen that increasing $^{\delta h}/w$ has a destabilizing effect.

The dihedral effect on static roll stability was investigated by testing the rectangular model with AR 4 wings attached with 5° of dihedral along the entire span. For this test $^{\delta h}/w$ was zero. The results for $^h/w$ = .060 are shown in Fig. 11. Roll stability for this configuration is approximately that for the no-wings configuration, so the dihedral had a pronounced destabilizing effect.

Selection of Wing

In choosing a wing planform and a wing attachment position ($^{\delta h}/w$) for the modified C-W Air Car model, several factors were considered:

(1) the hover tests of the rectangular model indicate that of the three wing planforms AR 6 is best from the points of view of hover performance and static roll stability, (2) any $\delta h/w$ involves a trade-off between performance and roll stability, (3) wing dihedral for the modified C-W Air Car is very desirable to avoid catching a wing tip while maneuvering, (4) construction difficulties are greatest for AR 6 wings, and (5) problems of storage and maneuvering in close spaces grow with aspect ratio. Since the tests indicate that the stabilizing effect of AR 6 wings would be largely lost with dihedral incorporated, and because of the last two factors cited above, it was decided to consider the AR 2 and AR 4 wings for the modified C-W Air Car.

The hover tests to investigate the effects of $\dot{\delta} h/w$ were all conducted with AR 4 wings on the model. The same tests were repeated for $\delta h/w$'s of .030 and .060 for the model with AR 2 wings. Fig. 12 compares the AR 2 and AR 4 wing-configured models with $\delta h/w = .060$ in hover performance and in roll stability at $h/w = .060$. The AR 4 configuration is a shade better with respect to roll stability, while the difference in hover performance is within the magnitude of experimental error. The same comparisons are made in Fig. 13, but with the wings attached at $\delta h/w = .030$. Here there is no difference in stability, and the AR 4 configuration is slightly better performance-wise at low h/w's.

These slight advantages of using AR 4 wings, plus the advantage in cruising flight of higher C_L and lower C_D, led to choosing AR 4 wings for the modified C-W Air Car model.

In choosing a wing attachment height (δh) for the modified C-W

Air Car, a factor other than lift augmentation and static roll stability was considered. In order to ensure adequate clearance between the wing and the ground, it was felt that the modified C-W Air Car should have a δh of at least 1 ft. For the scale model tests a $\delta h/w$ of .129 was provided. Thus a gain would be accrued in hover performance at a cost of accepting some roll destabilization.

A dihedral of 6^{o} was built in to the modified model for the reason previously discussed.

Hover Tests - C-W Air Car model

A series of hover tests were made using a scaled model of the C-W Air Car - completely unmodified. Then the same tests were repeated using the same model but with wings and aerodynamically-shaped nose and tail fairings added. The nose and tail surfaces were faired tangent to the top surface of the model but were joined a distance $\delta h/w = .045$ from the model base. This was to ensure adequate ground clearance for these surfaces. It also would reduce the effect of vorticity on the nose and tail fairings so that hover performance should benefit. The disadvantage of an increment of drag as a consequence of not streamlining tangent to the base was accepted.

The C-W Air Car has a skirt that surrounds the annular jet at the base of the machine. An attempt was made to provide a scaled model skirt of like flexibility by using a simple band of pressure-sensitive tape around the outside of the model base for the hover tests. It was found to be extremely difficult to match the actual skirt. Matching the C-W

Air Car skirt flexibility at cruise was found to be even more difficult, so for the wind tunnel work the model was tested without a skirt. It was felt, though, that this would not detract from the essential results of the wind tunnel tests.

The results of these hover tests are shown in Fig. 14 and 15. Hover performance in Fig. 14 is very slightly better for the modified C-W Air Car model but the difference is admittedly within the range of possible experimental error. Static roll stability comparisons are made in Fig. 15 at $^{h}/w$'s of .029 and .058. At $^{h}/w$ = .029 the stabilities are the same, while at $^{h}/w$ = .058 the modifications appear to have been slightly destabilizing at the higher roll angles. But most interesting is that at both ground heights the models appear to have some static roll stability.

Wind tunnel tests - C-W Air Car Model

The first configuration to be wind tunnel tested was the modified C-W Air Car fuselage alone with no wings or horizontal tail. The test height ($^{h}/w$) of .058 allowed an angle of attack variation of $\pm$ 2.5 degrees. Results of this test - lift, drag, and static longitudinal stability - are shown in Fig. 16, 17, and 18. Fig. 16 shows that for positive fuselage angles of attack (α) the lift curve slope is essentially linear with a slope of .11 per degree. Compared with a normal aircraft fuselage this value is high. This is because the reference area used in calculating C_L was the wing area with 100% fuselage carry-through. Use of an area which includes fuselage base area would produce

a C_L of about 40% of the value presented above. It was felt, however, that there was little to be gained by comparing this vehicle with an airplane.

Pitching moment (C_m) versus angle of attack (α) curves are plotted in Fig. 17 and appear to be linear up to $\alpha = 1^{\circ}$. In Fig. 18 C_m vs C_L is non-linear but quite stable throughout.

Addition of a horizontal tail with an incidence (i_t) of $+2^{\circ}$ had little or no effect on the lift curve slope of the vehicle. It is clear that at this incidence angle the horizontal tail was lifting downward. In order to measure pitching moments one model support was located on the horizontal tail. For the no-wings, no-tail run the model support was attached to a ¼-inch rod in place of the horizontal tail. It was felt that the reduction in C_D shown in Fig. 16 was the result of streamlining attained by replacing this rod with a horizontal tail of about the same maximum thickness.

Fig. 17 and 18 show that the addition of the horizontal tail had little effect on longitudinal stability. This was not undesirable since the tail was added only to provide control. It was noted, however, that C_m vs C_L became somewhat more linear.

For the purpose of providing trim information the data in Fig. 19 was collected. From these curves

$$\frac{\Delta C_m}{\Delta i_t} = - .014/_{\text{deg.}} \quad \text{average}$$

Next under consideration was the effect of addition of wings to

the vehicle. The test height ($\frac{h}{w}$) was maintained at .058. Fig. 16 shows that an average lift increment (ΔC_L) of about .3 was realized by this modification. It was of interest, however, to further consider the effects of horizontal wing position with respect to the CG of the vehicle. With the wings in the forward position the wing aerodynamic center was ahead of the CG, so a reduction in stability was expected. This is shown to be the case in Fig. 17 and 18. Here again C_m versus C_L was non-linear. For $C_L < .9$ the static stability ($^{dC_m}/dC_L$) was approximately -.44, and for $C_L > .9$, $^{dC_m}/dC_L \doteq -.14$. The lift curve slope for the wings-forward configuration was .15/deg. for positive angles of attack.

With the wings shifted a good distance aft of the vehicle CG a stability increase was realized as shown in Fig. 17 and 18. It is interesting to note that the pitching moment curves were linear up to a C_L of about .9 which corresponded to an α of $+1^\circ$. $^{dC_m}/dC_L$ for this range was -.625. Above C_L of .9 an instability began to develop. Also of interest was the fact that the lift curve slope for this configuration (Fig. 16) was reduced to a value of .085/deg. Possibly the boundary layer growth along the side of the fuselage had progressed enough so as to increase interference at the wing root and thus reduce lift. Further, it is possible that the standing vortex from the annular jet well ahead of the wing might have rolled up and over the top of the wing near the root causing premature separation of flow. These two reasons for reduction of C_L could be looked into more closely by the use of smoke tunnel analysis or pressure distribution analysis.

It would seem appropriate at this time to consider a little more in

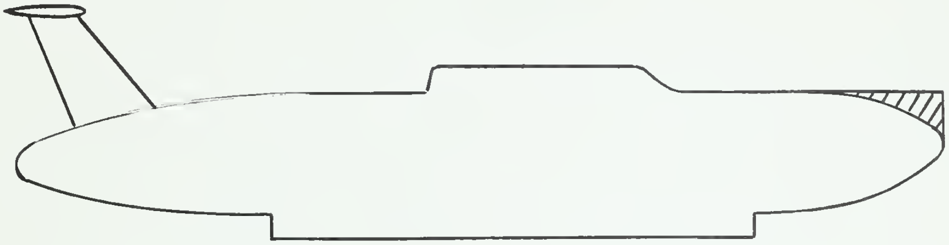
detail the rather sudden decrease in stability or "pitch-up" which occurred at a C_L of .9 ($\alpha = + 1^o$). Referring to Fig. 17 it is shown that this instability began to manifest itself on all configurations at an angle of attack of about $+1^o$. Noteworthy is the fact that the pitch-up was accentuated in the wings aft configuration as shown in Fig. 18.

At first glance it was felt that for the no-wing and wing-forward configurations, the reductions in angle of attack stability shown in Fig. 17 were due to a tendency for the nose of the vehicle to begin lifting at positive angle of attack. There were no evidences of stall in the lift curves, so pitch-up due to stall was ruled out. With the wings aft it was felt that the previously mentioned annular jet vortex action ahead of the wing, which was a possible cause of the large reduction in C_{L_α}, could also be responsible for the accentuated pitch-up tendency.

Wing incidence (i_W) was varied from -5^o to $+5^o$ in an effort to learn more about wing influences on the unstable tendency. Fig. 19, 20, and 21 show the results of these tests. Angle of attack stability (C_{m_α}) and static stability (dC_m/dC_L) are shown in Fig. 20 and 22 to have been essentially unaffected by i_W for angles of attack less than $+1^o$ and C_L less than .9. For the case where wing incidence was -5^o Fig. 20 and 22 show that the unstable tendency was reduced. For the $i_W = +5^o$ configuration the lift curve (Fig. 21) indicates a decay in lift at a C_L of 1.1. The moment curves show a corresponding accentuation of the pitch-up tendency. Thus it appears that the theory of annular jet standing vortex influence is further substantiated. From the curves in Fig. 20

$$\frac{\Delta C_m}{\Delta i_W}_{\text{average}} = -\ .018/\text{deg}$$

In order to investigate fuselage influence on instability, the nose fairing was modified as sketched below.



This particular modification was chosen to ensure that the flow on the upper surface was actually separated. Test runs were made with the wings-aft configuration at a height ($^h/w$) of .058. Fig. 21 shows that the lift curve slope was not materially affected, but that the expected loss in C_L and increase in C_D were realized. It was surprising, however, to note that the unstable tendency was completely eliminated as indicated in Fig. 22. This rather unexpected development would tend to cast some doubt upon the speculations made concerning the influence of the annular jet vortices ahead of the wing. Again the need for a smoke tunnel analysis is pointed up in order to ascertain for sure the existing flow patterns.

Vehicle power effects were then investigated, and results are shown graphically in Fig. 20, 23, and 24. As a result of shutting off the forward motor and covering the inlet it was discovered in comparing Fig. 21 (case of $i_W = 0^o$) and 23 that C_L was essentially unchanged throughout the angle of attack range. C_D was generally reduced by about .05. This reduction is considered to represent the decreases of momentum drag and

form drag connected with the annular jet air curtain. It is hoped that smoke tunnel analysis might give some insight as to the reason for the non-linearity of the lift curve (Fig. 23) for positive angle of attack. Fig. 24 indicates an increase of static stability ($^{dC_m}/dC_L$) to -1.05, but the unstable tendency at high C_L remained.

With both engines shut off and their inlets left open Fig. 23 shows a reduction in C_L and C_D of about .1 and .05 respectively compared with the wings-aft, full-power configuration (Fig. 21). The reasons for C_D reduction are no doubt the same as those mentioned for shutting down only one engine. The C_L reduction can be partially attributed to loss of lift augmentation. The moment curves of Fig. 20 and 23 are non-linear but stable throughout.

The final wind tunnel test at a height ($^h/w$) of .058 was run at a reduced dynamic pressure (q) in order to get an idea of the effect of forward velocity on static stability. As seen in Fig. 23 C_L was reduced by about 75%, C_D was halved, and though the lift curve remained linear, its slope was grossly reduced to about .02/deg. It would appear that at a reduced q the "sink" effect of the vehicle's engines is important to the cruise aerodynamics. As q decreases the sinks become stronger, and again smoke tunnel analysis may be the key to determining their effects on C_L and C_D. Additional wind tunnel tests on the modified fuselage alone at various q's might also be useful. Fig. 20 and 24 indicate a generally stable trend of pitching moments at large positive and negative angles of attack but a definite narrow instability range around zero angle of attack (C_L = .2).

To investigate the effects of ground height on vehicle performance the

runs in ground effect at $^h/w$ of .029, .117, and free stream runs were undertaken for comparison with the $^h/w$ = .058 runs. Results are shown in Fig. 25 through 30. In Fig. 25 the lift curve slope for the lower height was found to be the same. Also a slight increase in lift and a decrease in drag were realized. These trends seem to be compatible with those indicated in Ref. 3 for wings in ground effect. At the height ($^h/w$) of .117, however, the lift curve slope increased again possibly indicating that vehicle power effects had come into play. Comparisons of stability at these three heights, considered to be in ground effect, can be drawn from Fig. 26 and 27. It would appear that ground height does not materially affect the general trend of stability, but that increase in height may delay the onset of the pitch-up tendency. As shown in Fig. 27 unstable trends occurred at C_L's of .85, .9 and 1.3 as ground height was set at .029, .058, and .117 respectively. The free stream lift curve slopes shown in Fig. 28 were found to be about .083, and Fig. 29 and 30 indicate considerable reduction of static stability.

Also considered in the free stream tests were the effects of vehicle power and yaw. Fig. 28, 29 and 30 show that a yaw of 5^o has little effect on C_L, C_D, and C_{L_α}. Considering pitching moments, the yaw succeeds only in changing the trim but has no marked effect on longitudinal static stability. Vehicle power also is shown in these figures to have had little effect on lift curve slope and stability in free flight. Increases in C_L and C_D with addition of power can most likely be attributed to augmentation, momentum drag, and form drag among other things.

CONCLUSIONS AND RECOMMENDATIONS

The addition of wings to a GEM has the effect of reducing hover performance. As the chord of the wing is increased hovering performance is degraded. As the wing attachment height is increased hover performance improves toward that obtained for a wingless vehicle. With wing area kept constant static roll stability increases as wing aspect ratio increases to six. The effect of increasing attachment height is to decrease roll stability. Although dihedral is necessary for cruise maneuverability its effect is to reduce static roll stability.

In forward flight wings add lift as expected. Their contribution to static longitudinal stability, of course, depends upon their horizontal location with respect to the vehicle center of gravity. The aerodynamic shape of the nose has a profound effect on the vehicle's cruise performance and static longitudinal stability. Negative camber should be employed in order to greatly increase the angle of attack where lift from the nose causes undesirable reduction in longitudinal stability.

The wings-forward configuration is the more desirable in order to 1) reduce static longitudinal stability and increase control with the horizontal tail, and 2) reduce the annular jet standing vortex influence ahead of the wing by allowing it less room to develop.

In order to better understand cruise aerodynamics it is recommended that a smoke tunnel analysis of flow patterns be made.

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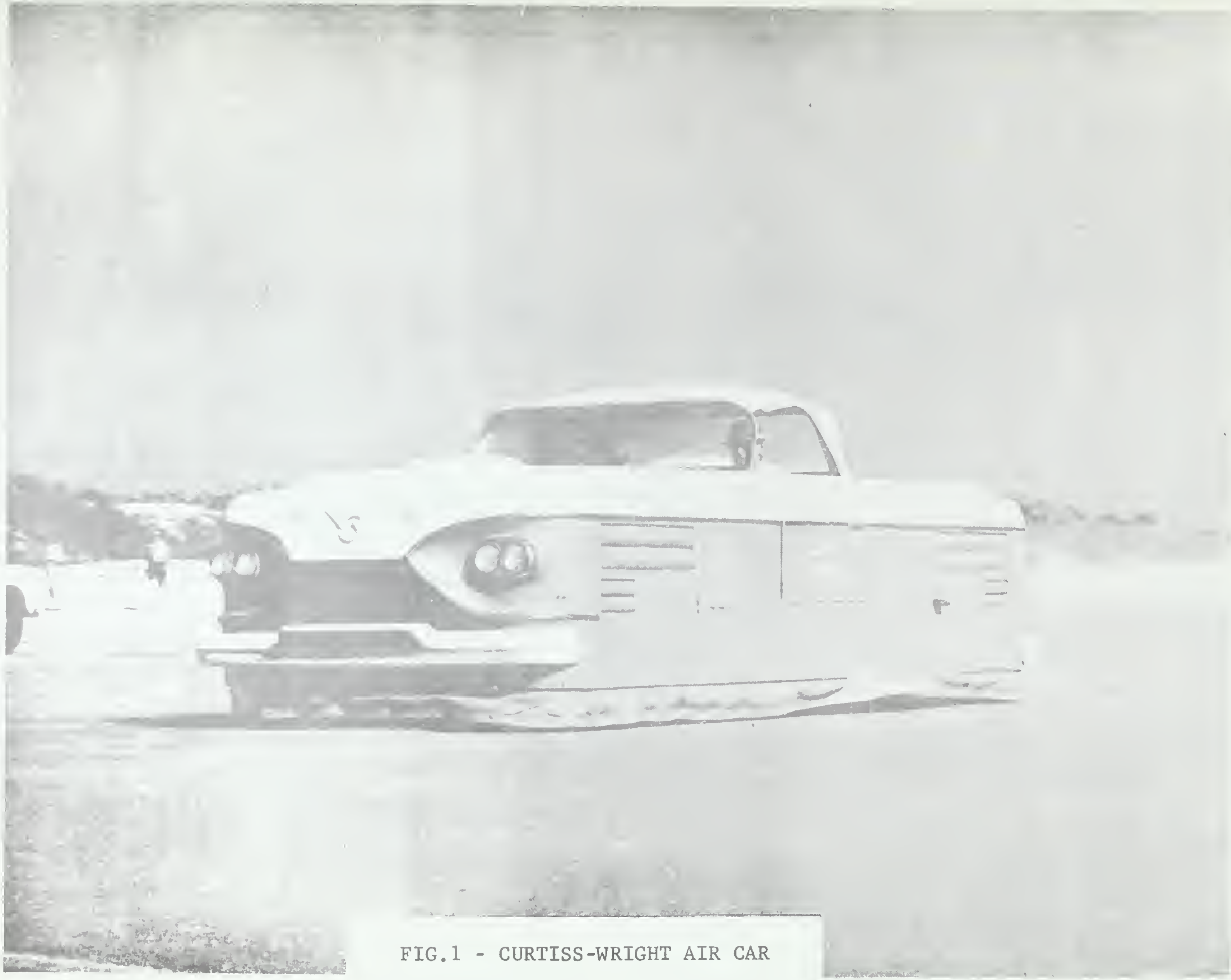
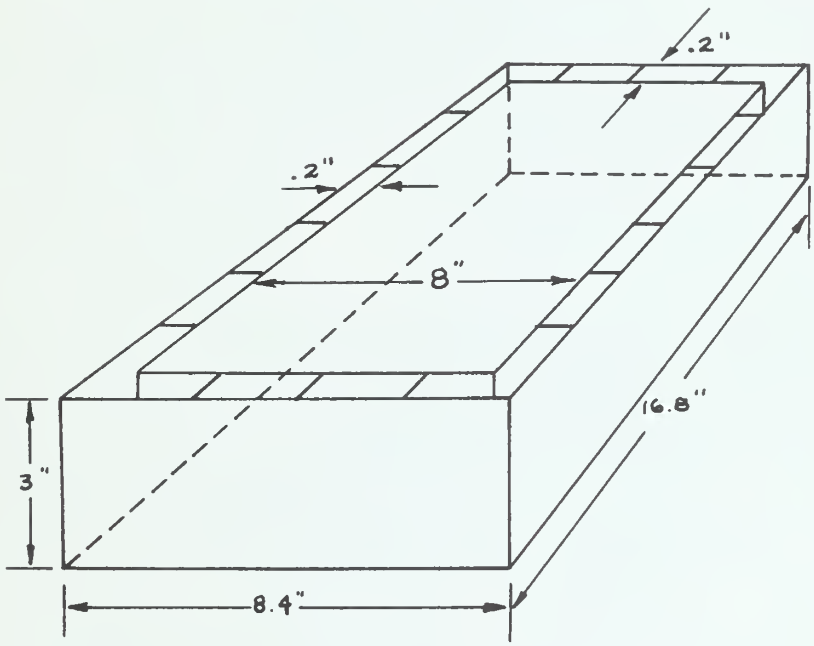


FIG.1 - CURTISS-WRIGHT AIR CAR

FIG. 2 - RECTANGULAR
ANNULAR JET MODEL



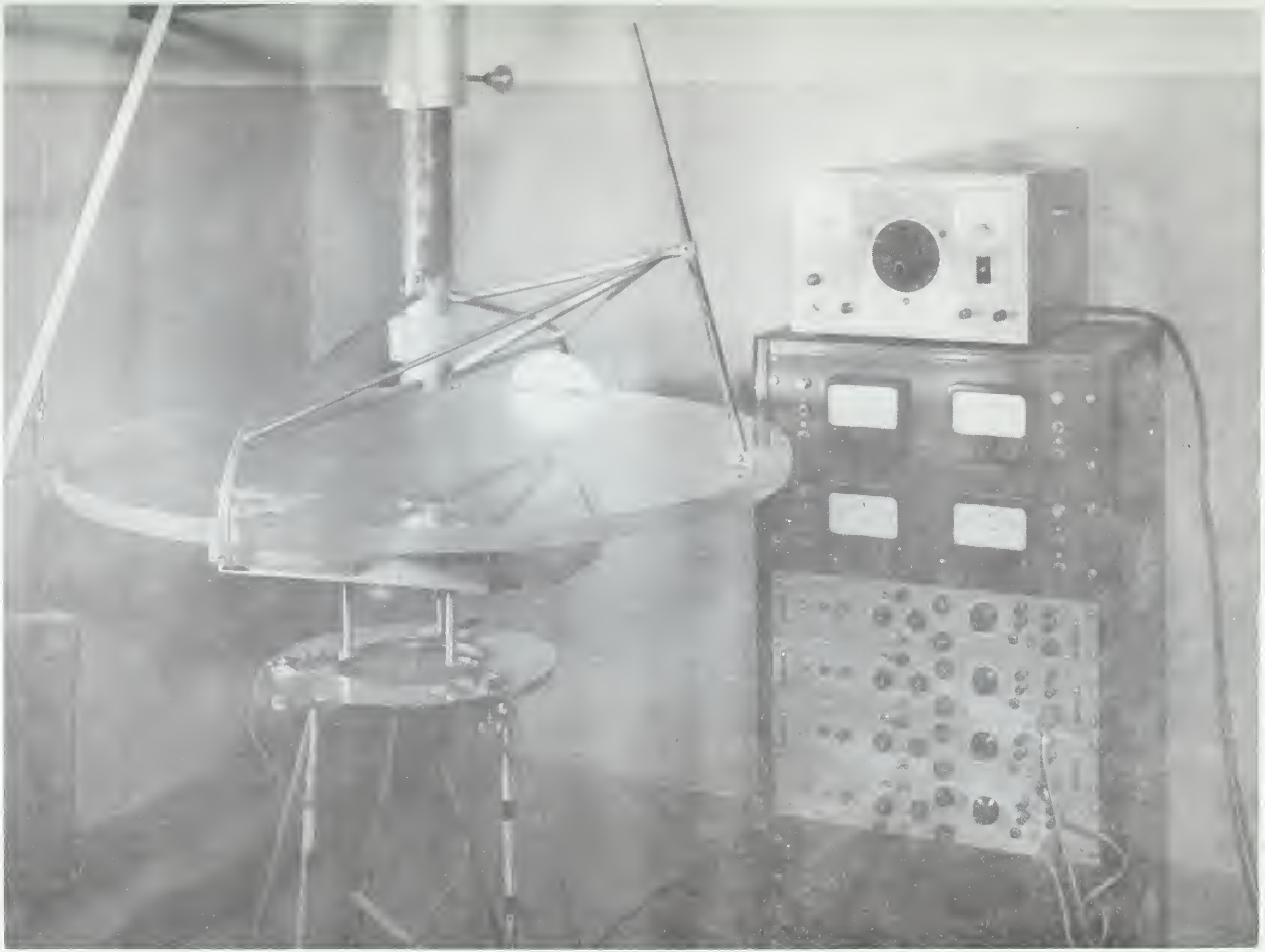


FIG.3 - STATIC HOVER TEST STAND

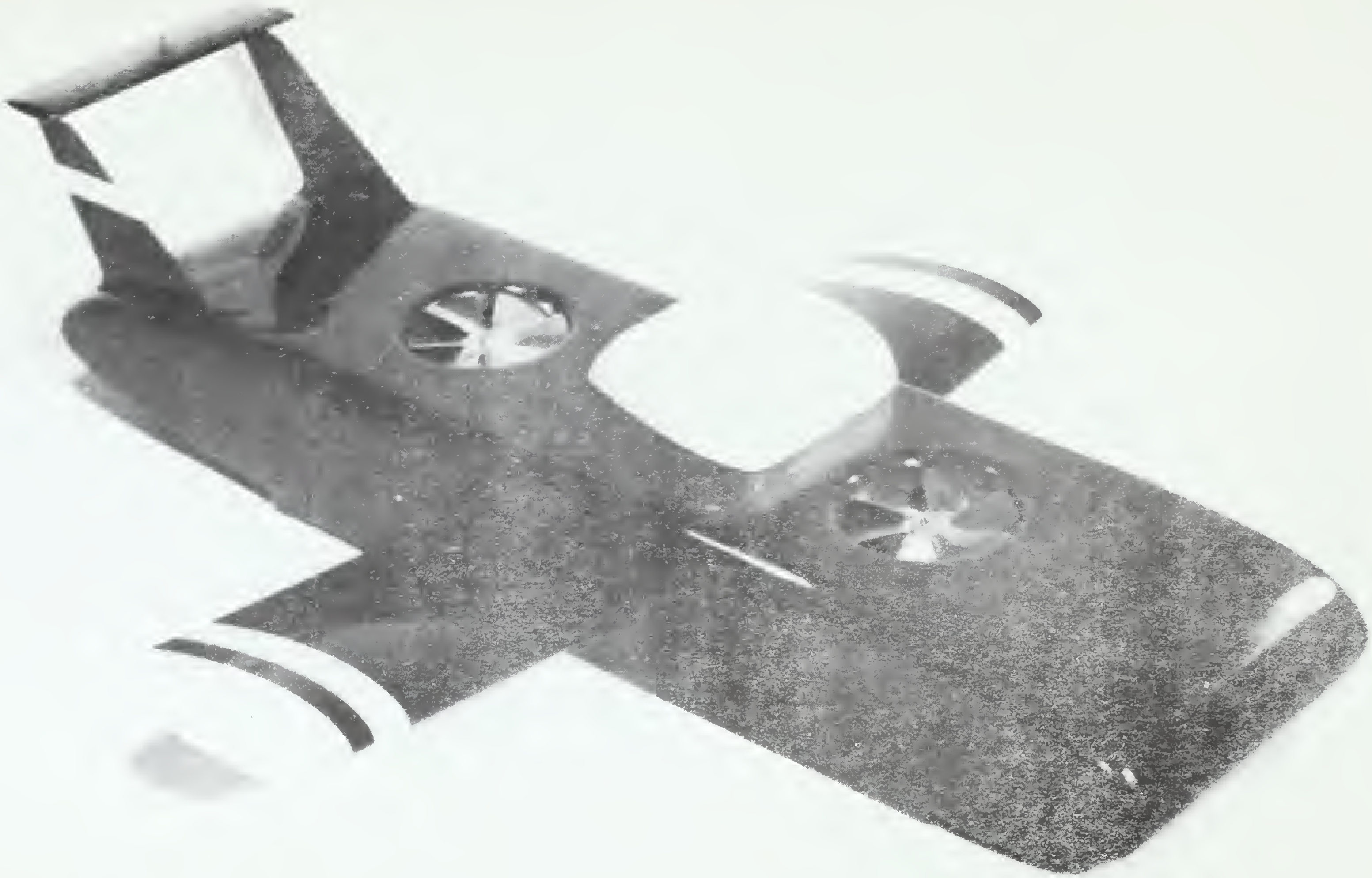


FIG.4 - MODIFIED CURTISS-WRIGHT AIR CAR MODEL

FIG. 5 - HOVER PERFORMANCE OF RECTANGULAR MODEL

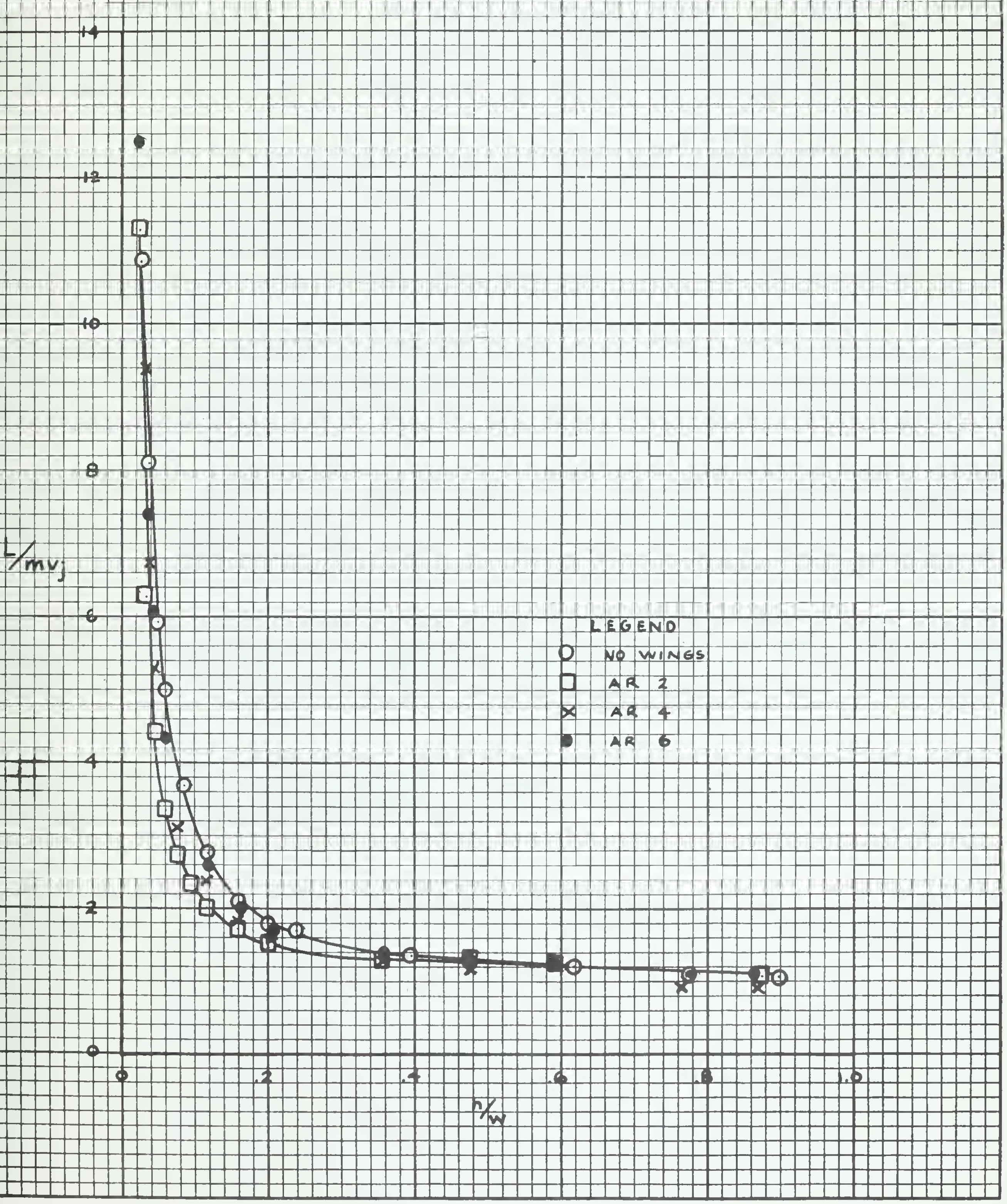


FIG. 6 – HOVER PERFORMANCE OF RECTANGULAR MODEL

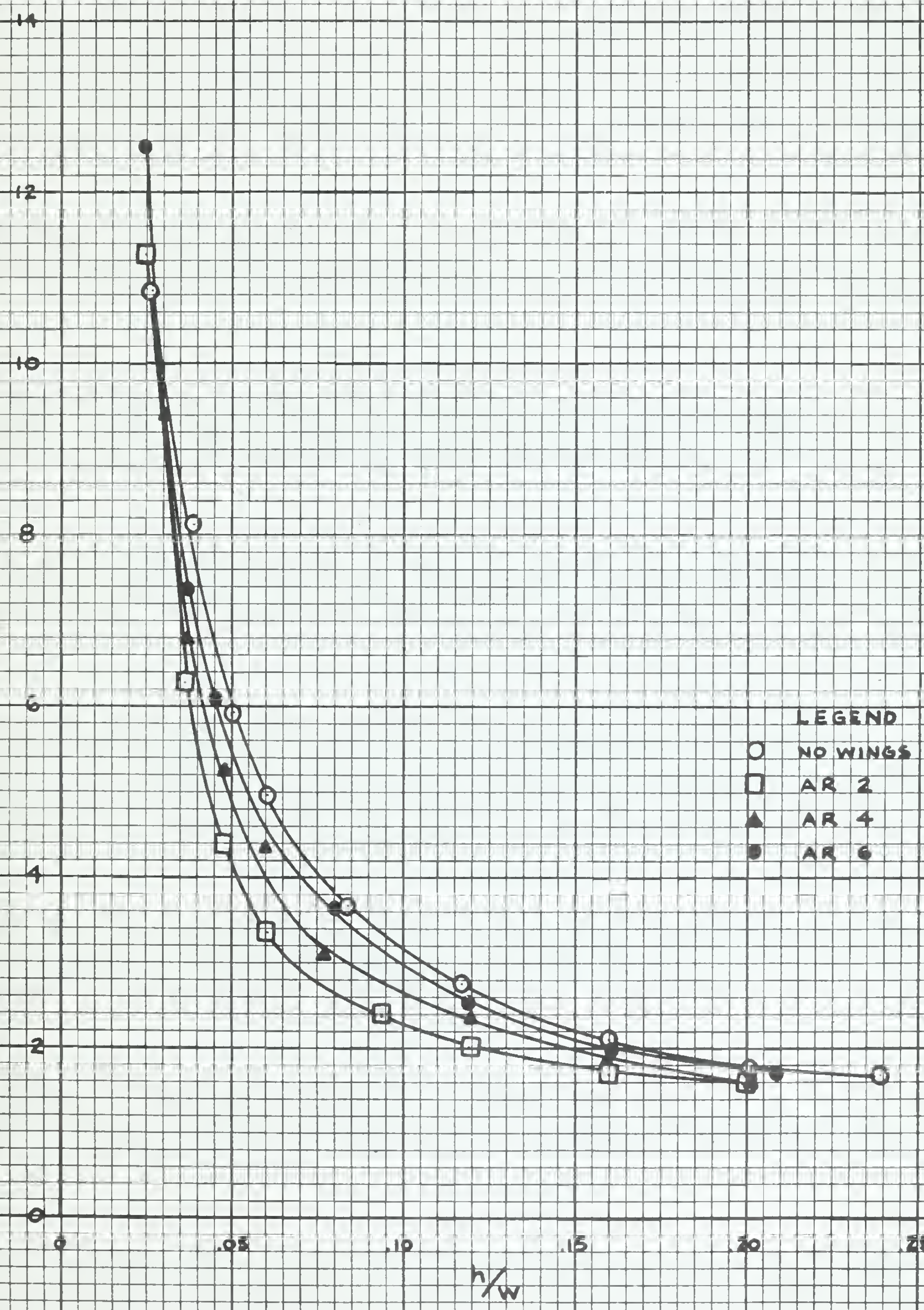
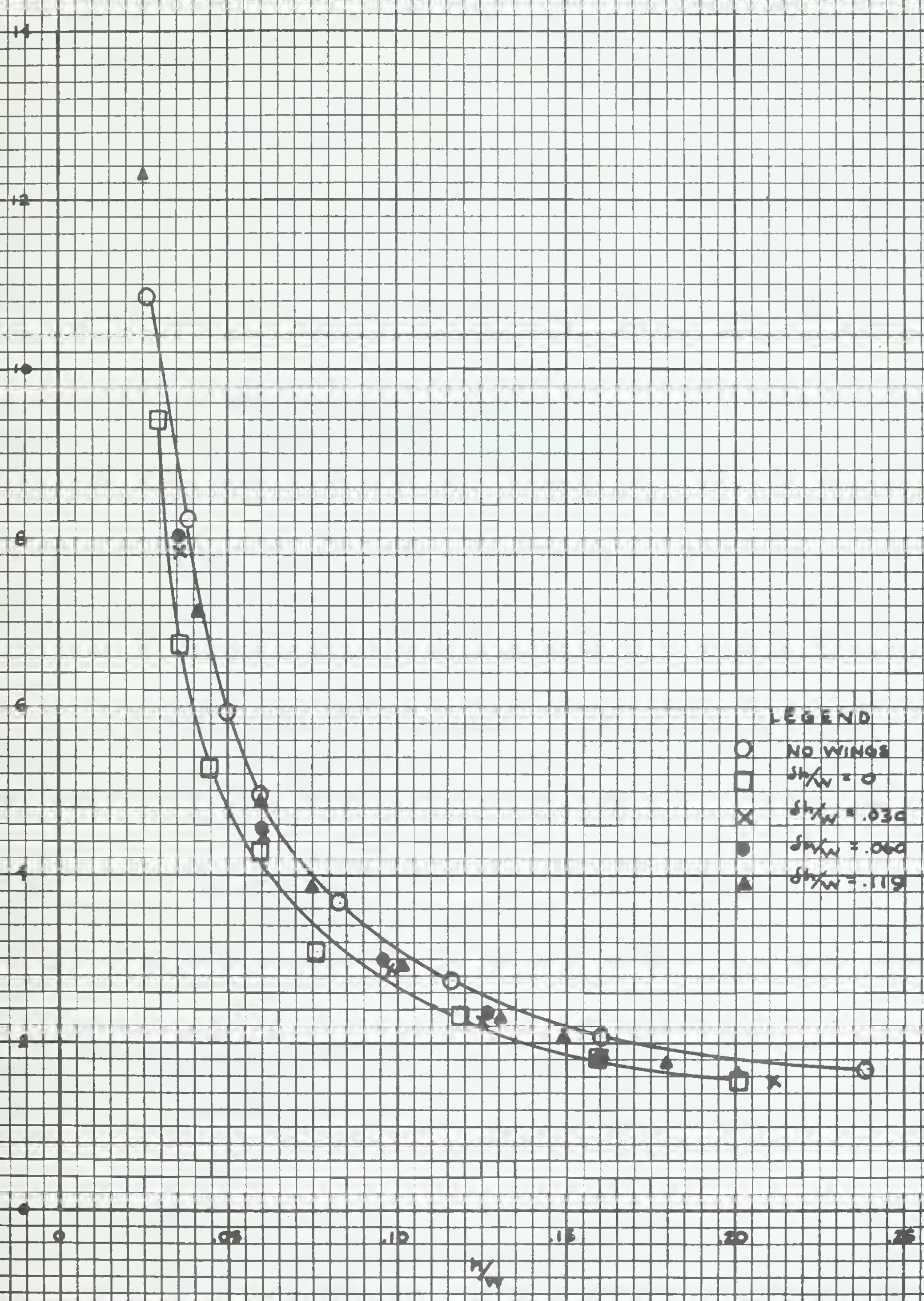


FIG. 7 - HOVER PERFORMANCE OF RECTANGULAR MODEL WITH WINGS ATTACHED AT DIFFERENT HEIGHT INCREMENTS



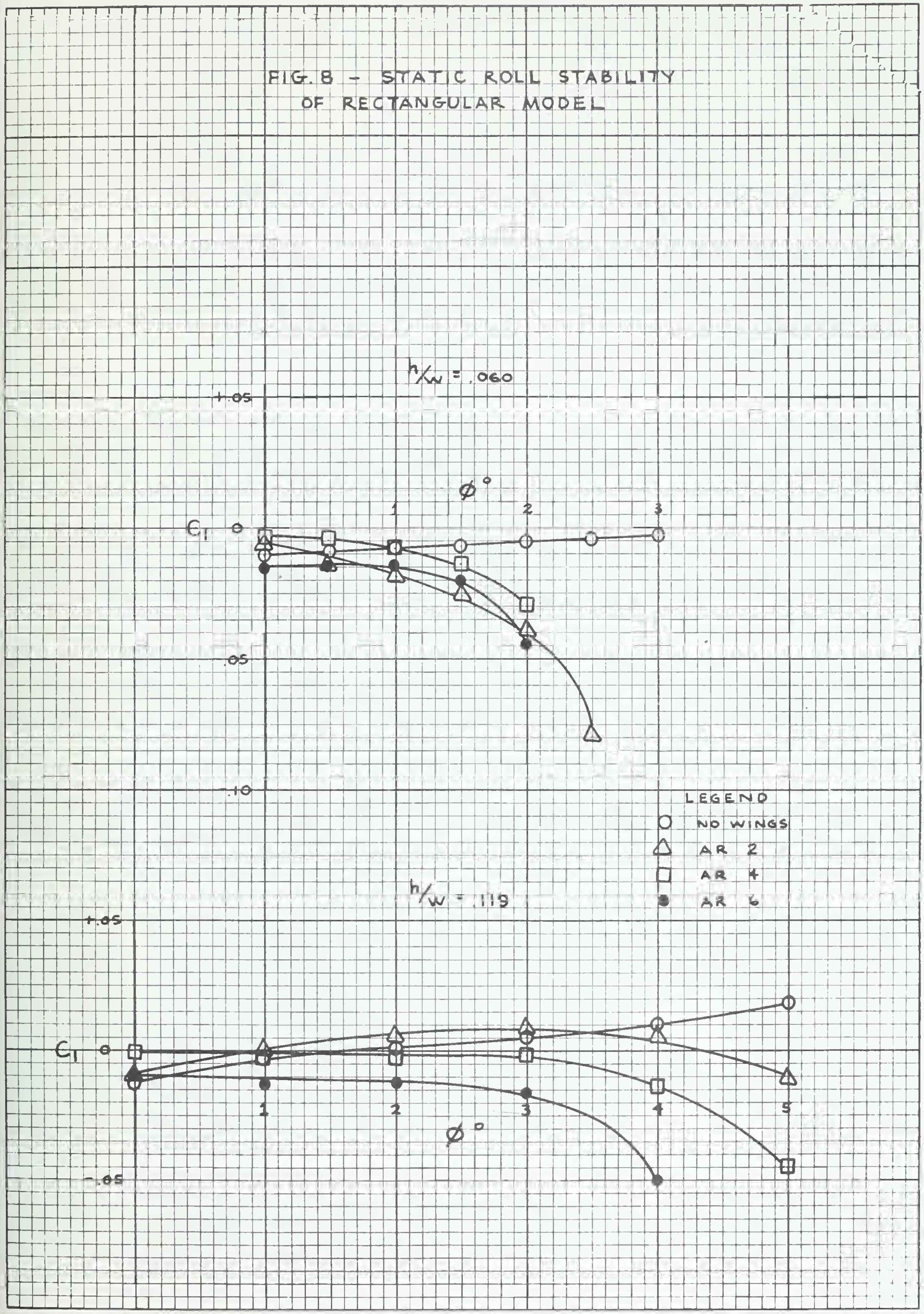
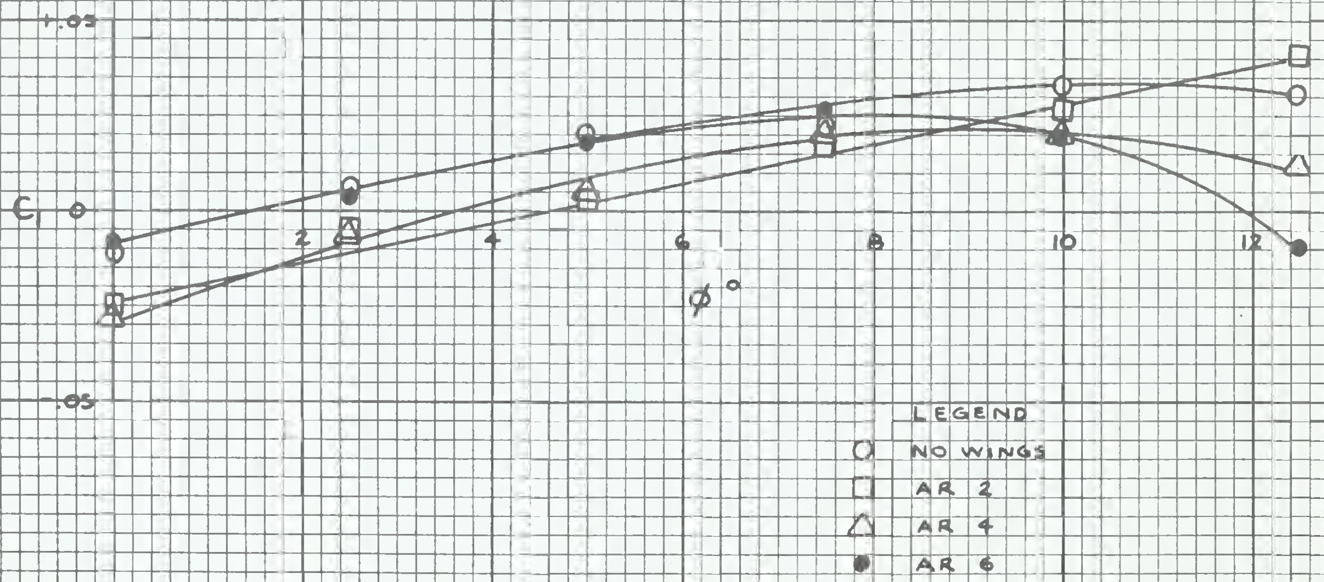


FIG. 8 - STATIC ROLL STABILITY
OF RECTANGULAR MODEL
h/w = .060
+.05
$\phi°$
1
2
3
C_l 0
.05
-.10
LEGEND
NO WINGS
AR 2
AR 4
AR 6
h/w = .119
+.05
C_l 0
1
2
3
4
5
$\phi°$
-.05

FIG. 9 – STATIC ROLL STABILITY OF RECTANGULAR MODEL AT $h/w = .359$



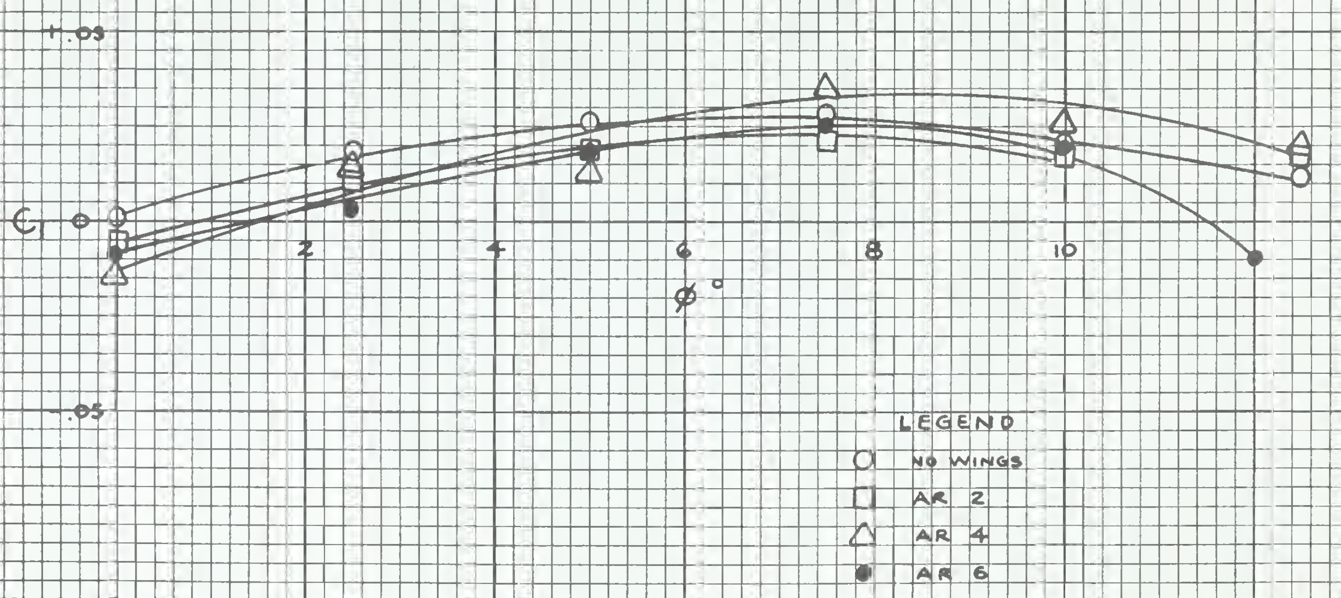
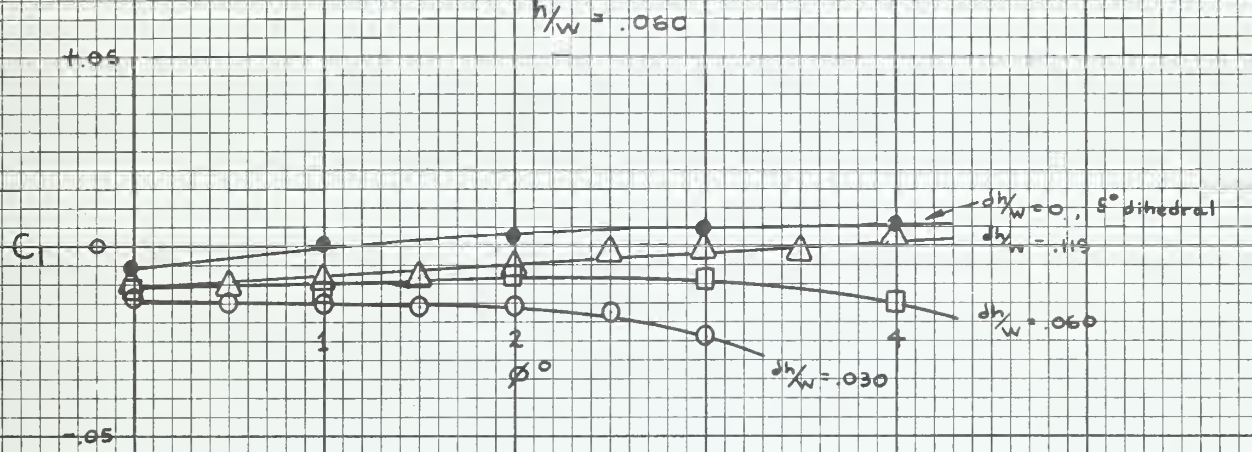


FIG. 10 — STATIC ROLL STABILITY OF RECTANGULAR MODEL AT h/w = .595

FIG. 11 – STATIC ROLL STABILITY OF RECTANGULAR MODEL WITH WINGS ATTACHED AT INCREMENTS ABOVE THE BASE



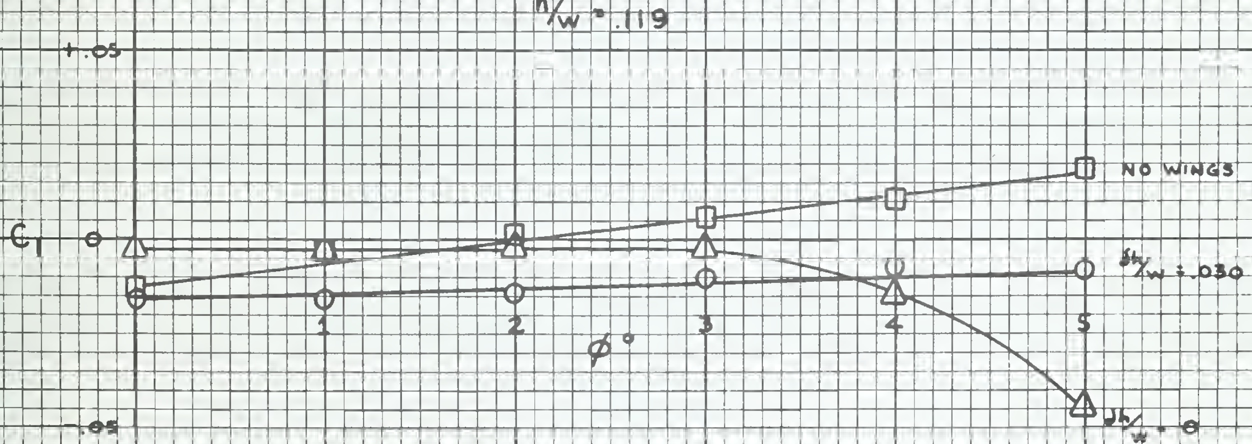


FIG. 12 - COMPARISON OF STATIC ROLL STABILITY AND HOVER PERFORMANCE OF RECTANGULAR MODEL WITH AR 2 AND AR 4 WINGS ATTACHED AT $d_h/w = .060$

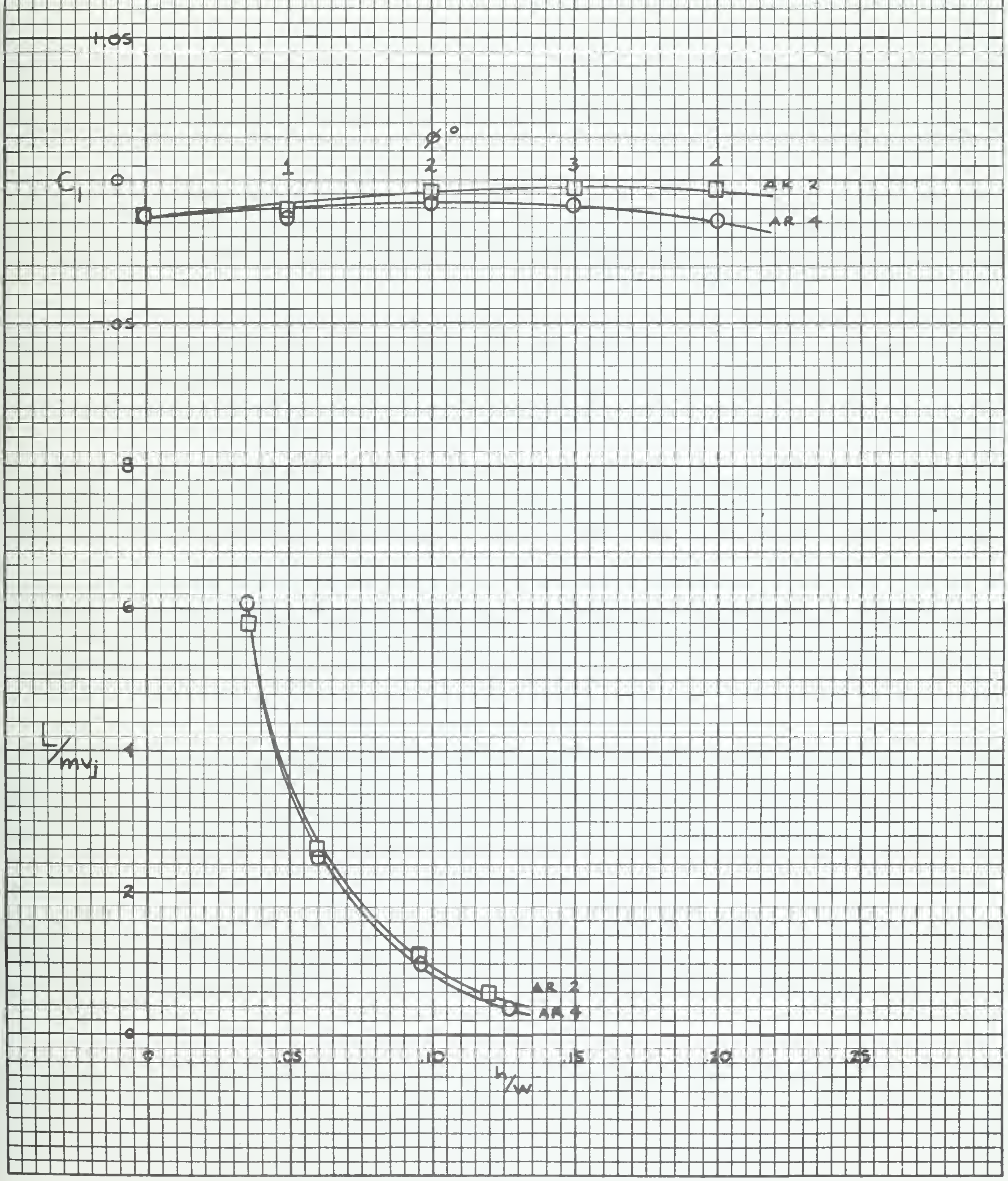
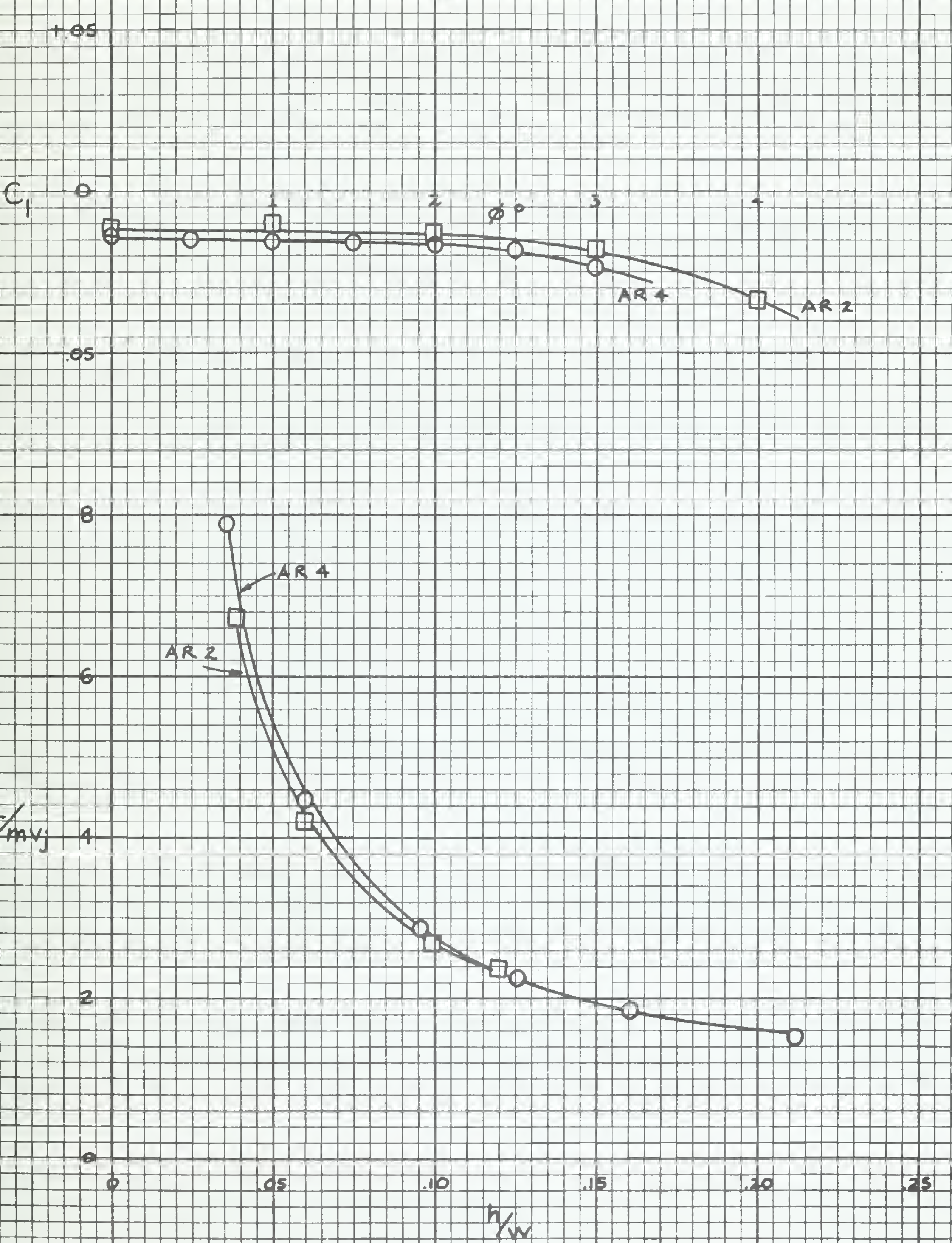


FIG. 13 – COMPARISON OF STATIC ROLL STABILITY AND HOVER PERFORMANCE OF RECTANGULAR MODEL WITH AR 2 AND AR 4 WINGS ATTACHED AT $^{\delta h}/_{W}$ = .030



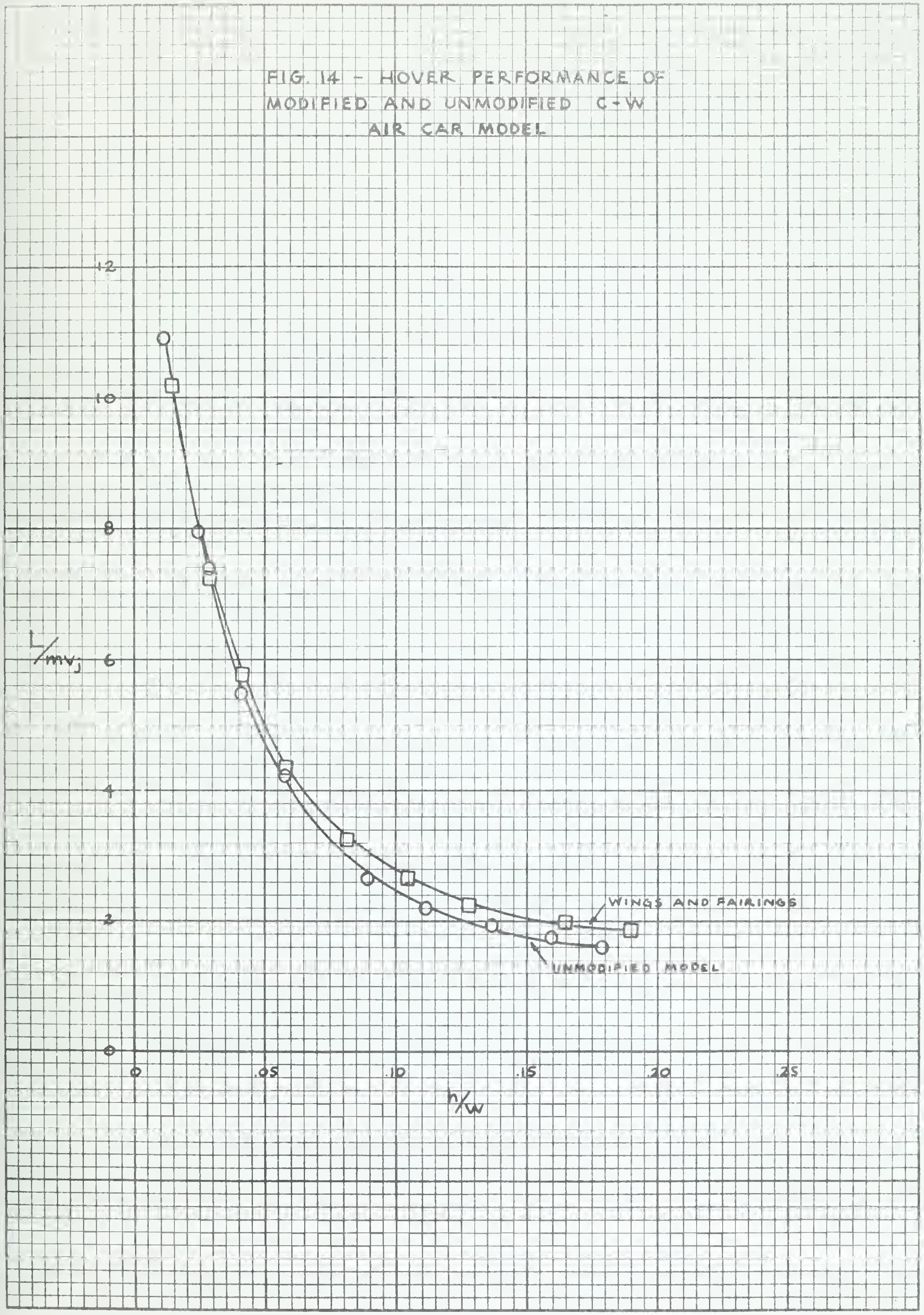


FIG. 14 - HOVER PERFORMANCE OF
MODIFIED AND UNMODIFIED C-W
AIR CAR MODEL
12
10
8
L/mv_j
6
4
2
0
0
.05
.10
.15
.20
.25
h/w
WINGS AND FAIRINGS
UNMODIFIED MODEL

FIG. 15 - STATIC ROLL STABILITY OF MODIFIED AND UNMODIFIED C-W AIR CAR MODEL

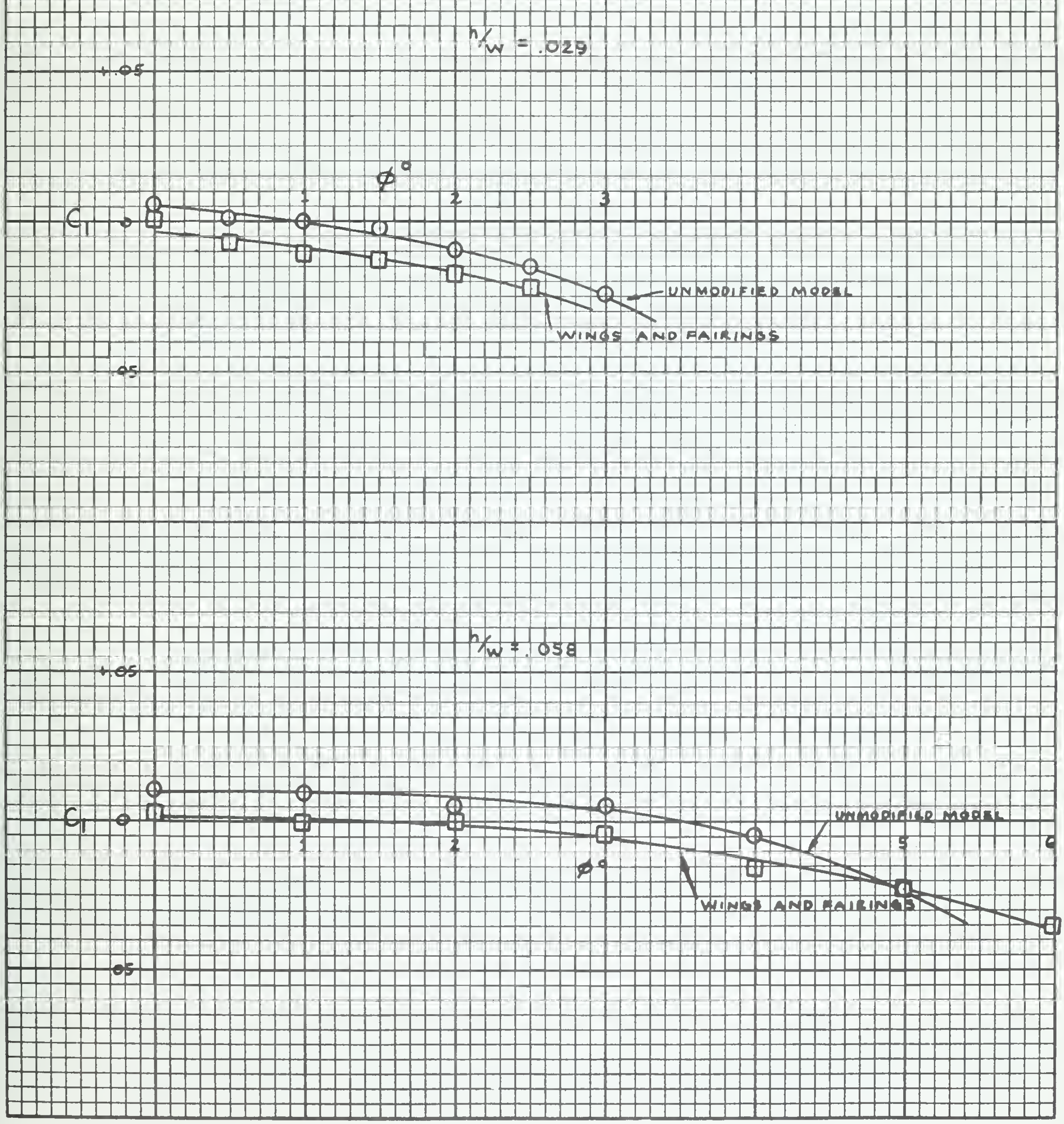


Fig. 16 - Modified C-W Air Car model. Lift & drag curves for various configurations

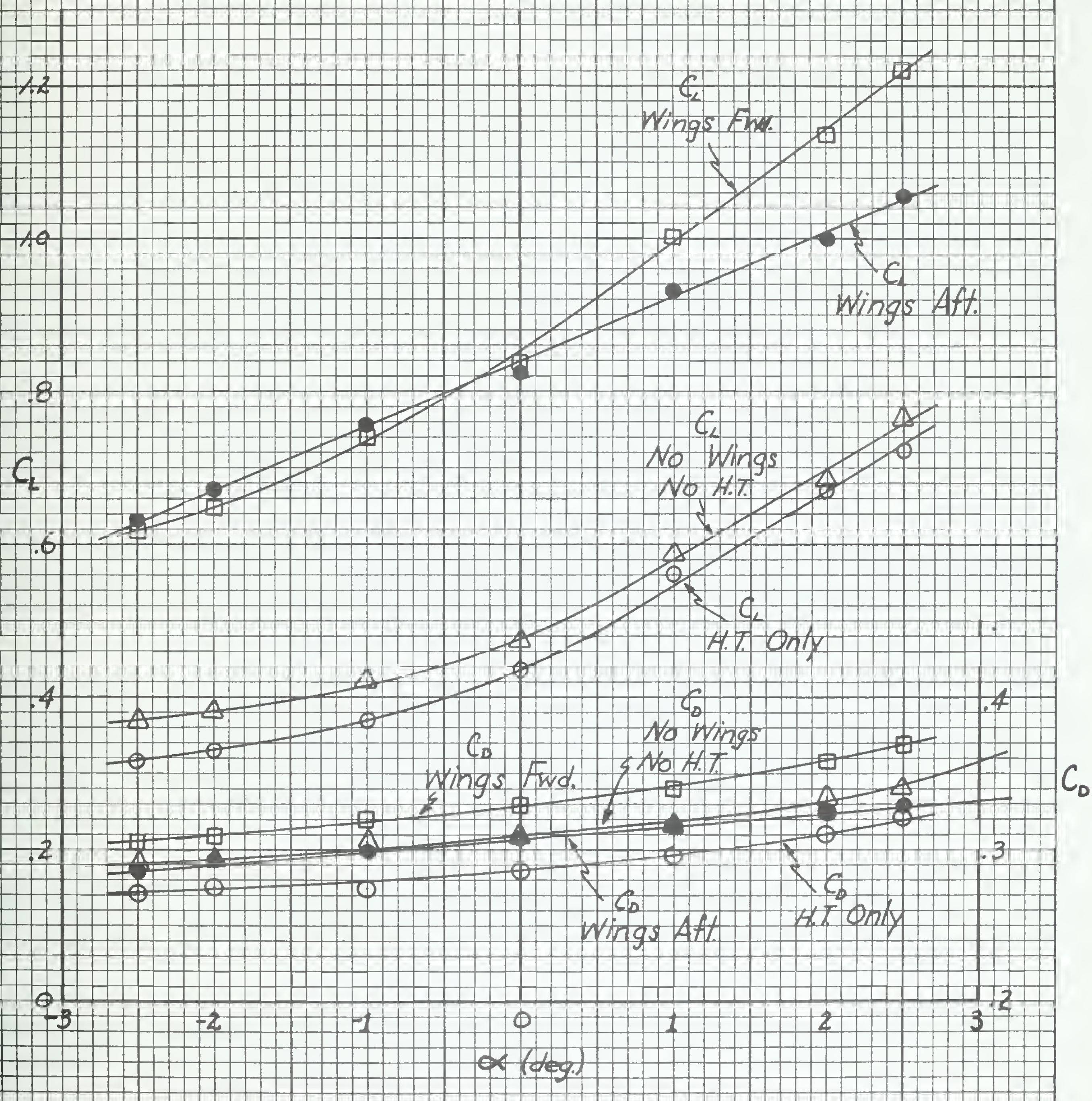


Fig. 17 - Modified C-W Air Car model.
C_m vs α for various configurations.

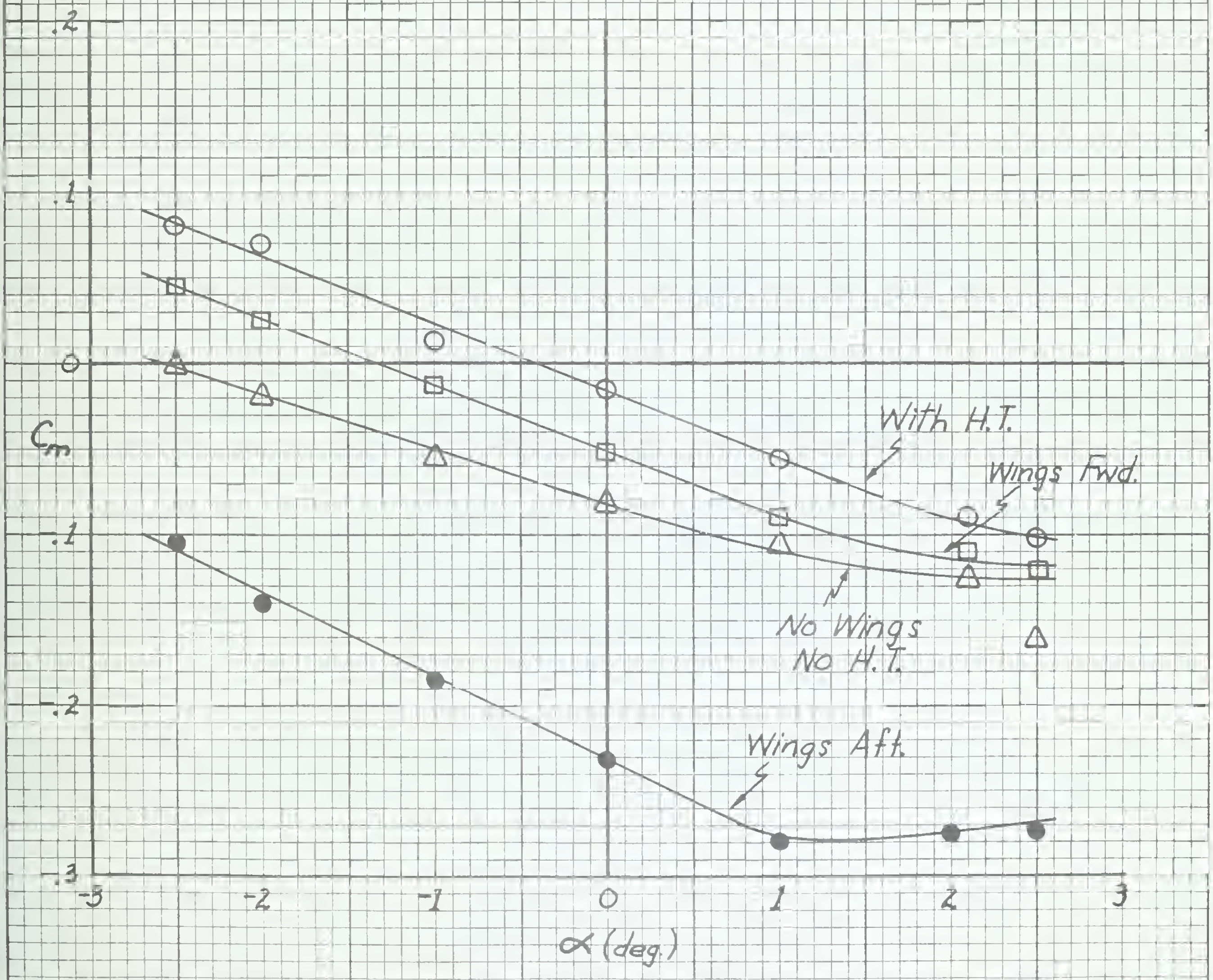


Fig. 18 - Modified C-W Air Car model.
Static stability for various configurations.

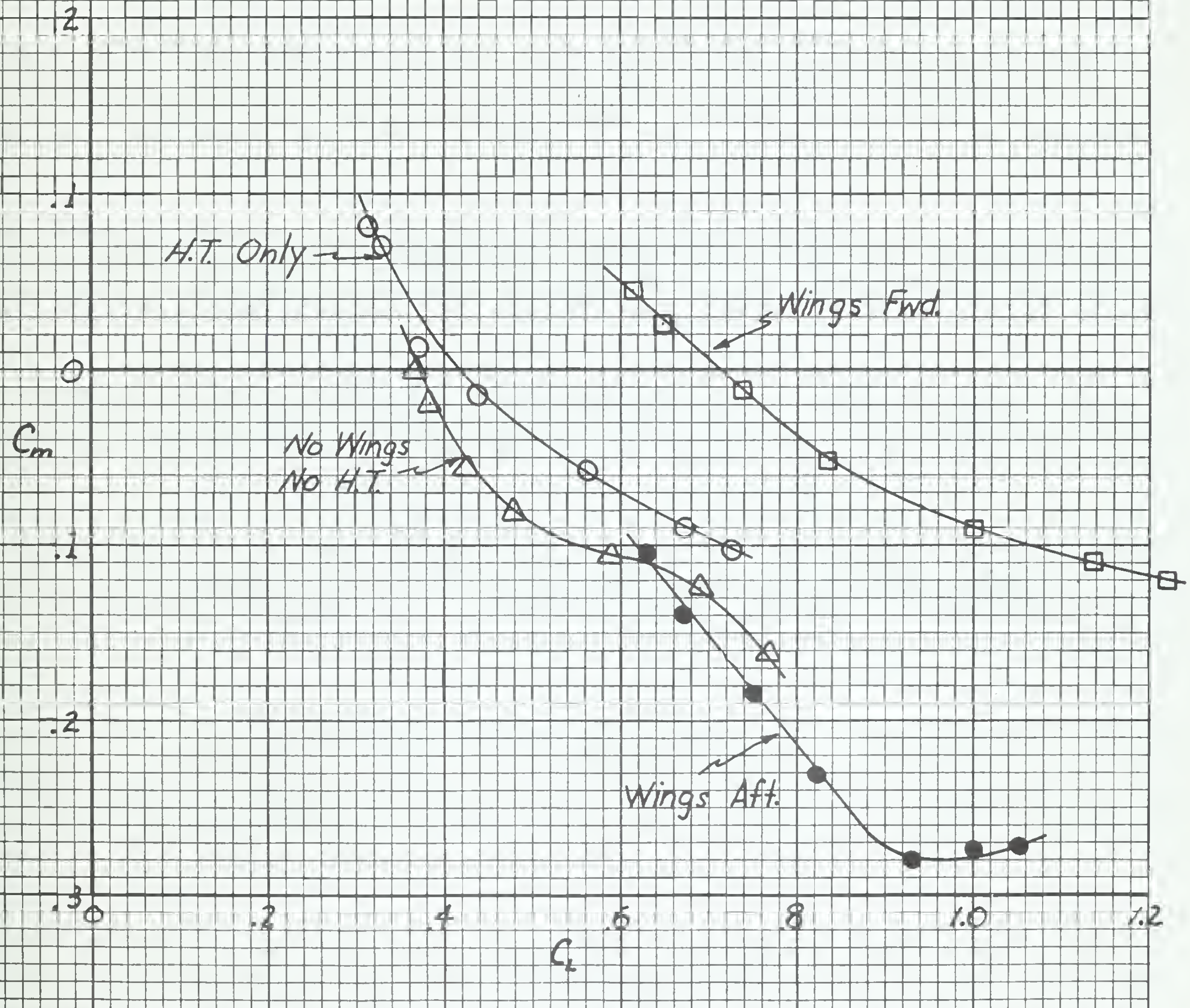
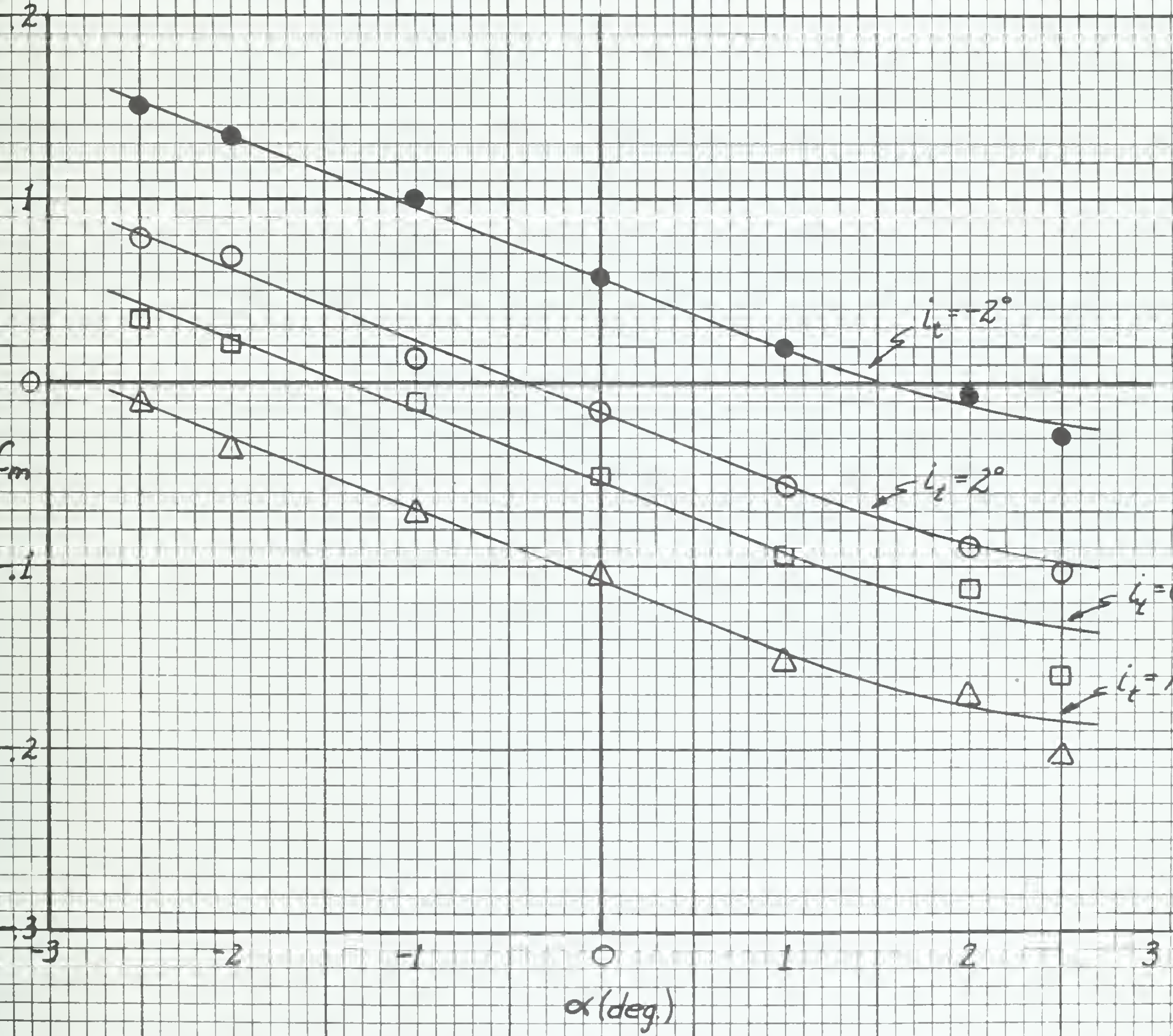


Fig 19 - Modified C-W Air Car model.
Tail incidence effects.



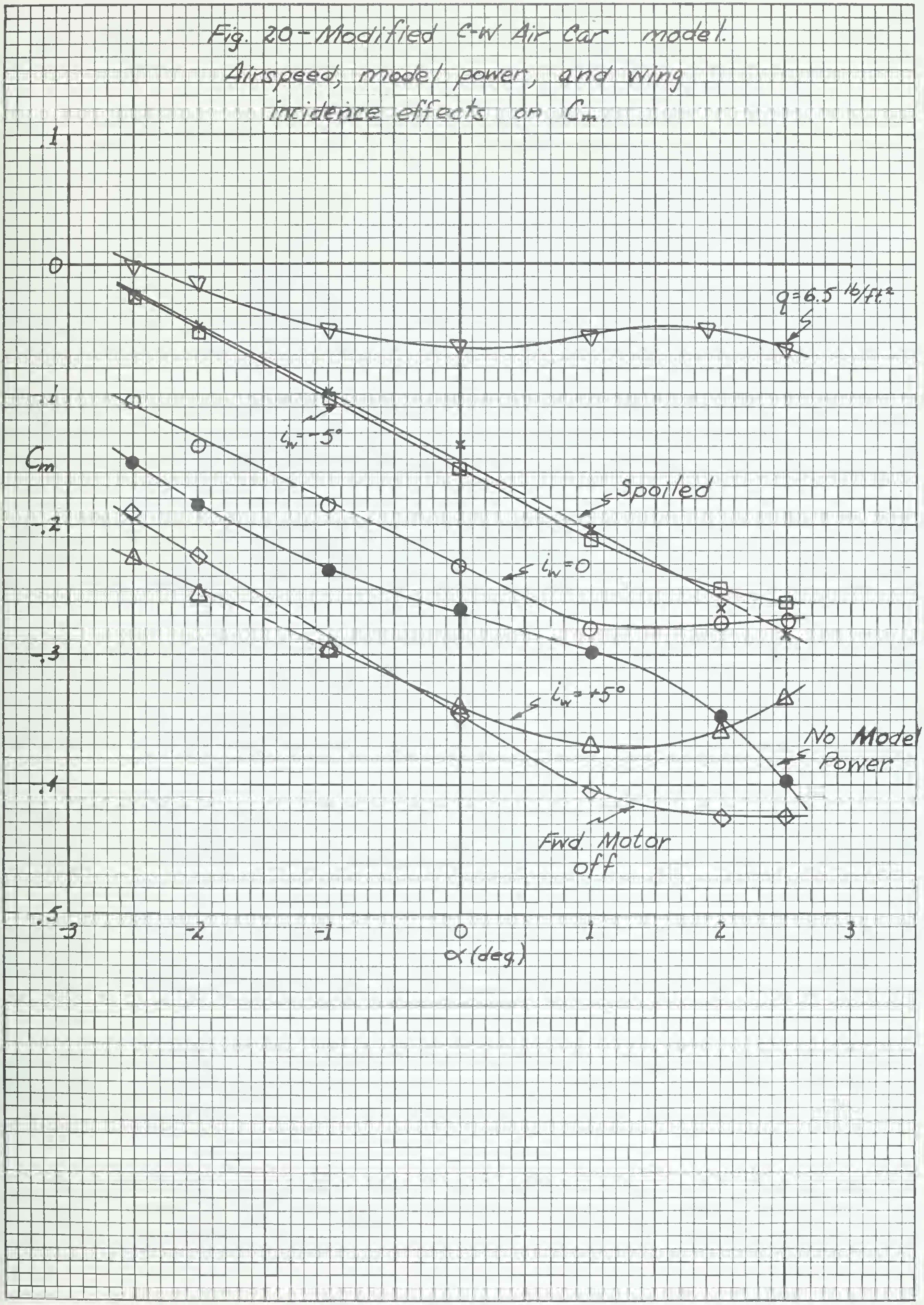


Fig. 20 - Modified C-W Air Car model.
Airspeed, model power, and wing incidence effects on C_m.
C_m
.1
0
-.1
-.2
-.3
-.4
-.5
-3
-2
-1
0
1
2
3
α (deg)
$q = 6.5$ lb/ft²
$i_w = -5°$
Spoiled
$i_w = 0$
$i_w = +5°$
No Model Power
Fwd. Motor off

Fig. 21 - Modified C-W Air Car model.
Lift & drag for various wing incidences
and modified nose.

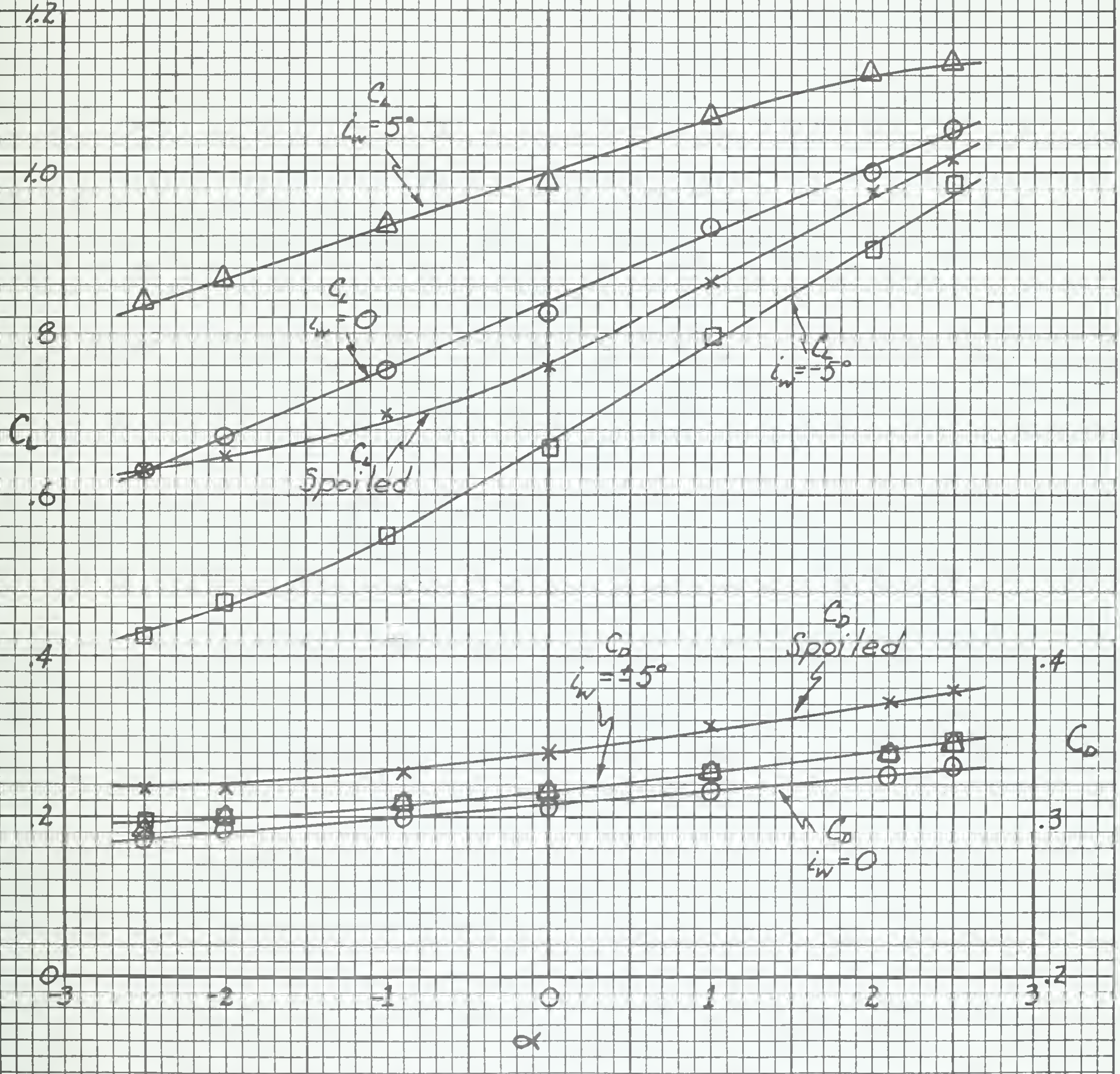


Fig. 22 - Modified C-W Air Car model.
Static stability for various wing incidences
and modified nose.

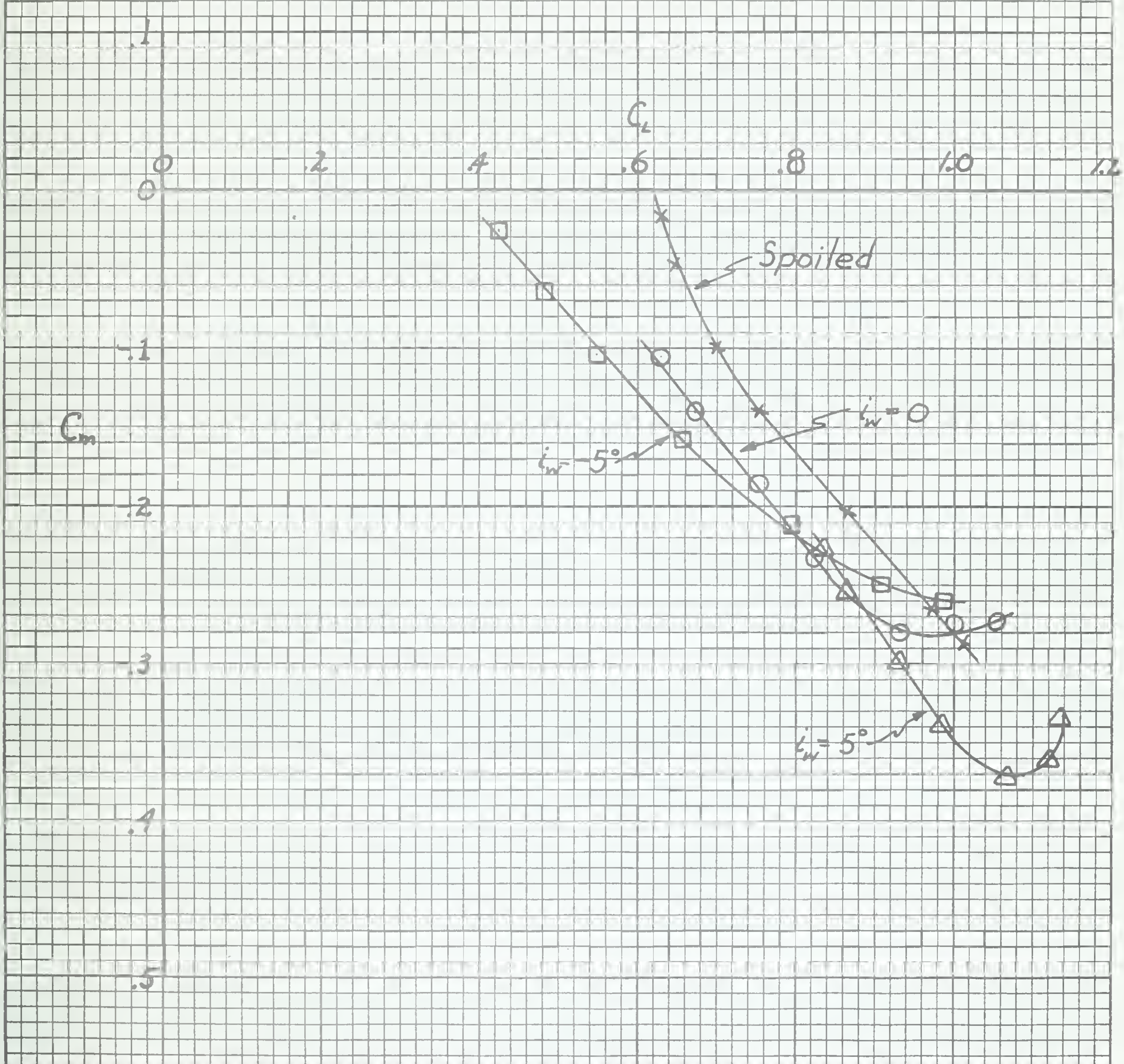
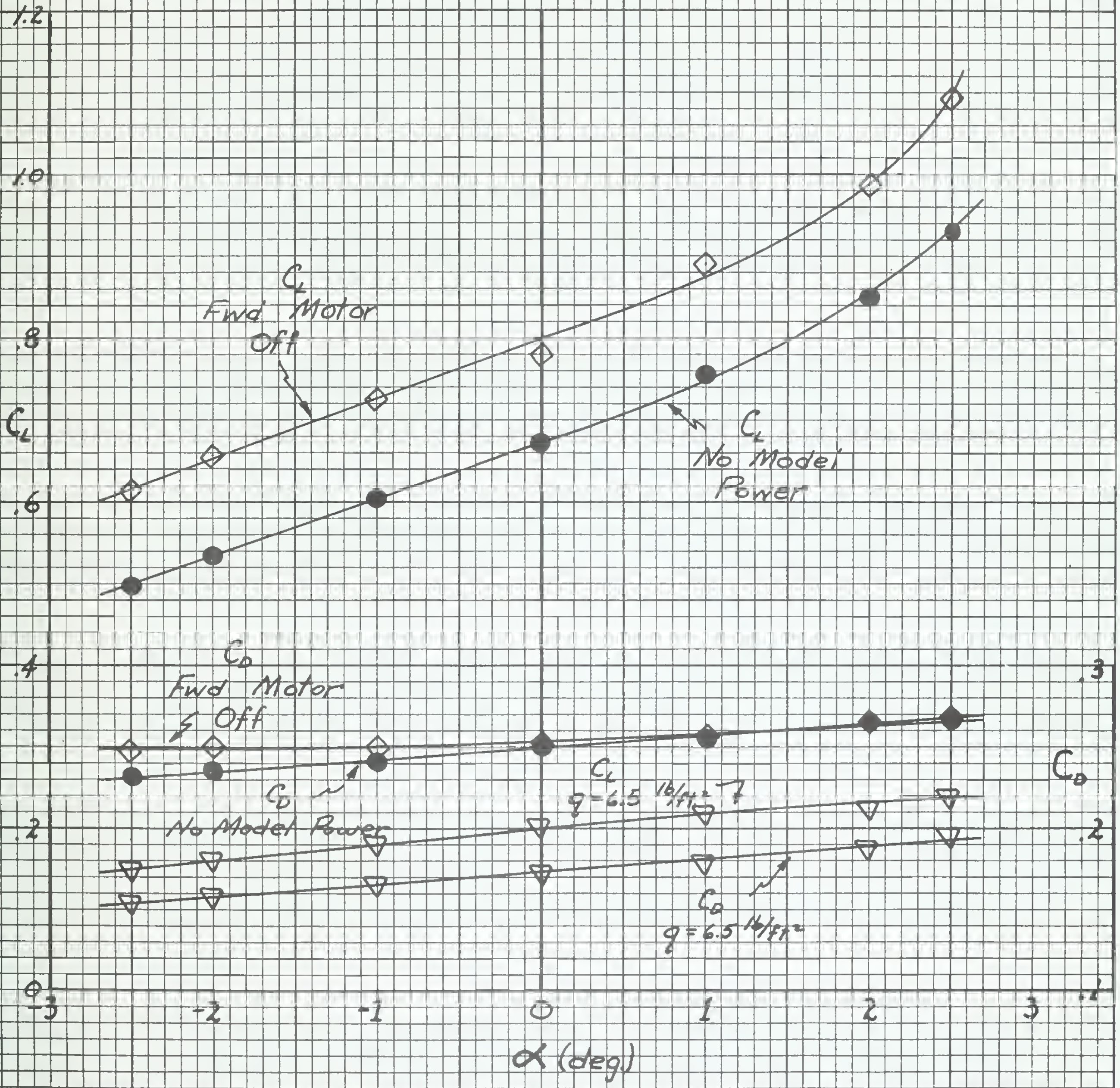


Fig. 23 - Modified C-W Air Car model. Lift & drag for varying model power and airspeed.



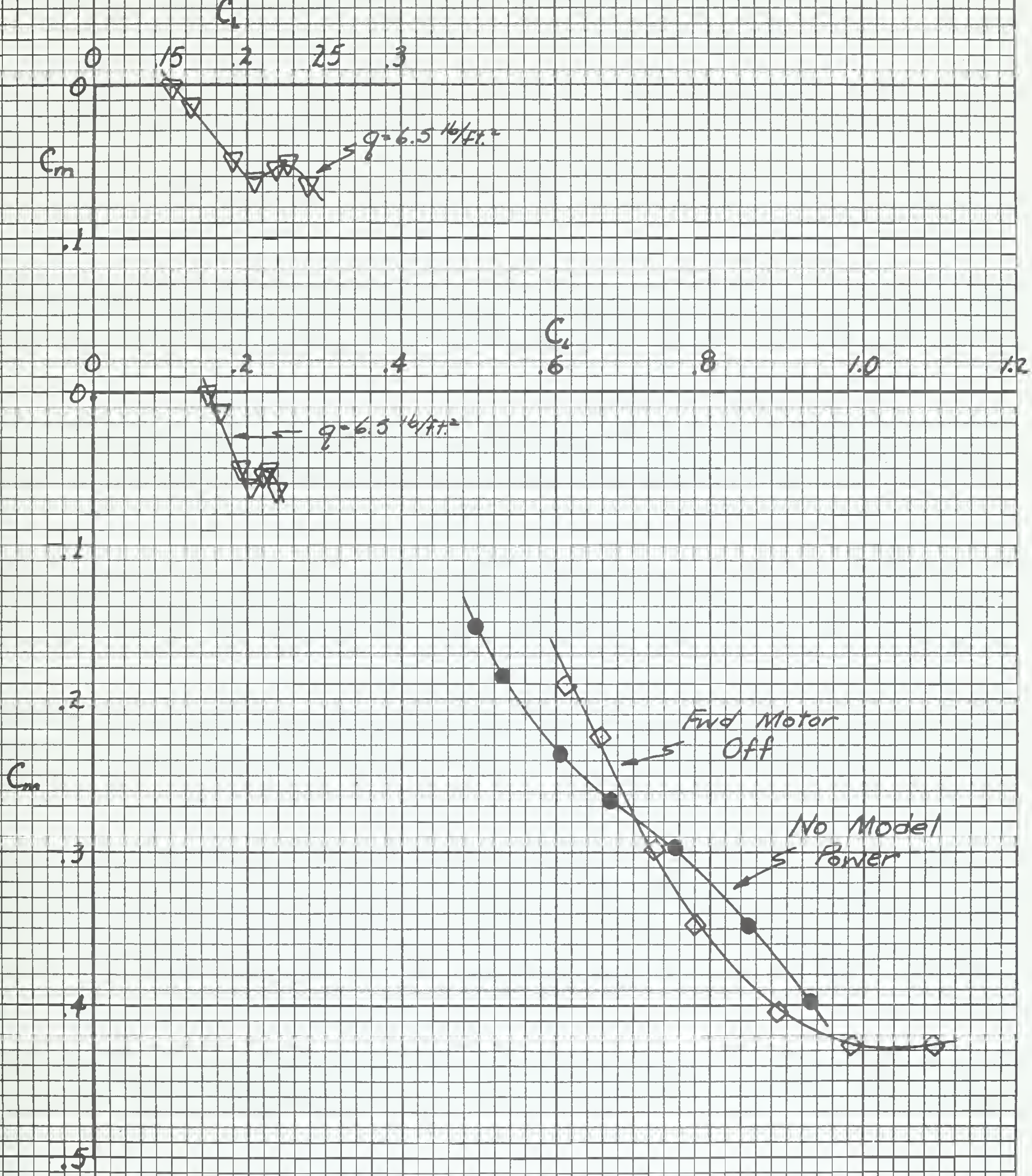
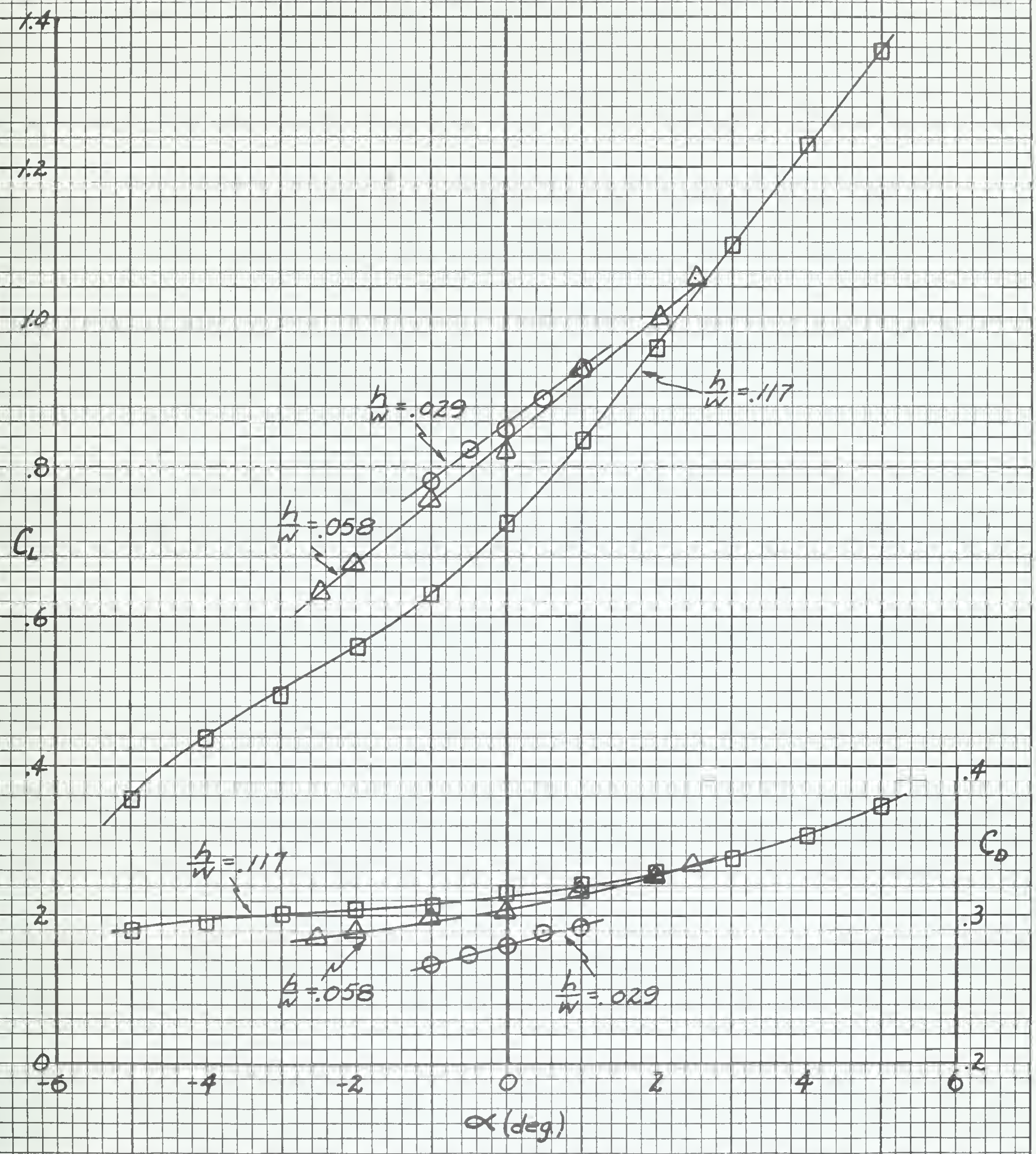


Fig. 24- Modified C-W Air Car model.
Static stability for varying model power and airspeed

Fig. 25 - Modified C-W Air Car model.
Lift & drag for various model heights.



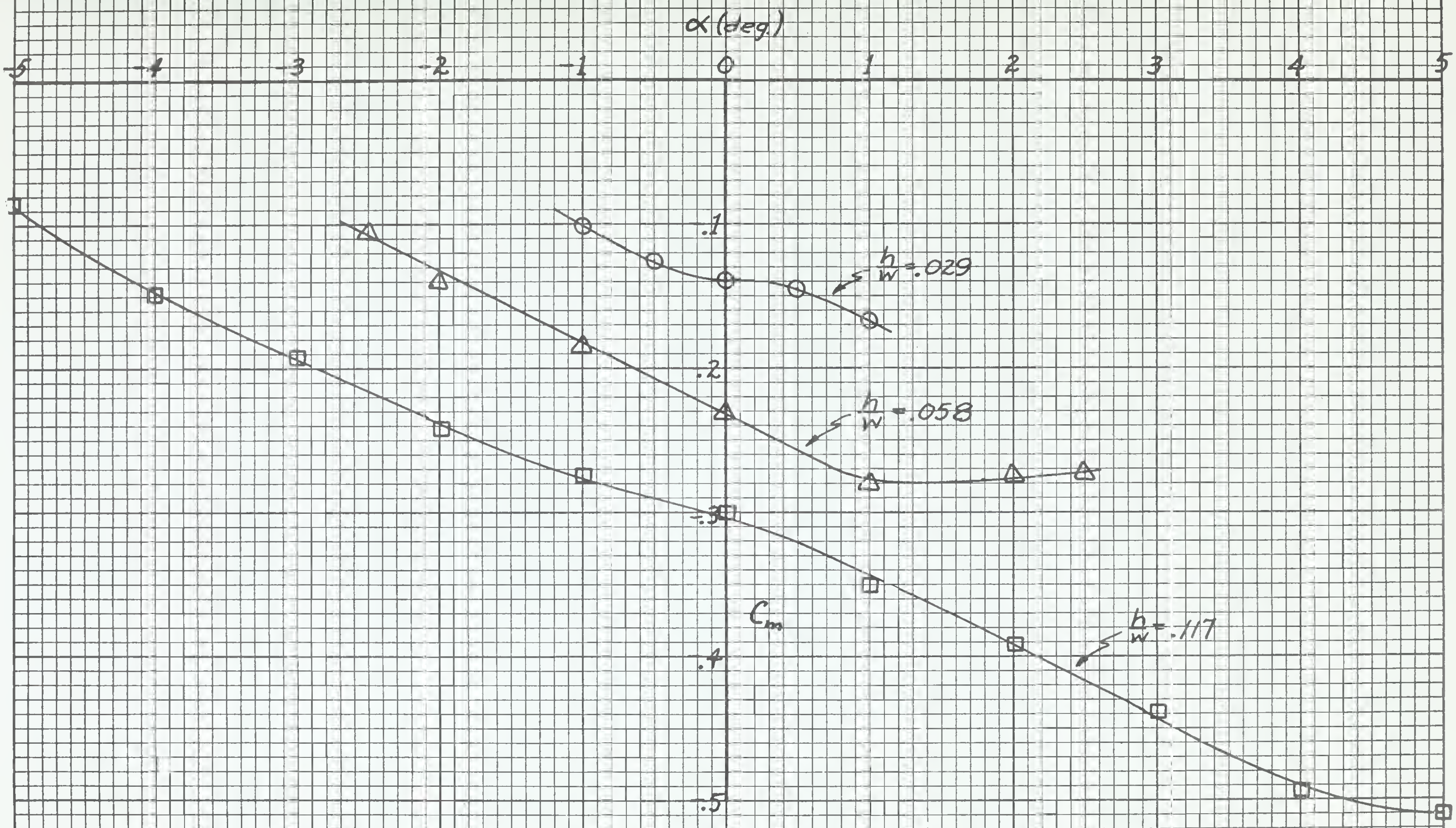
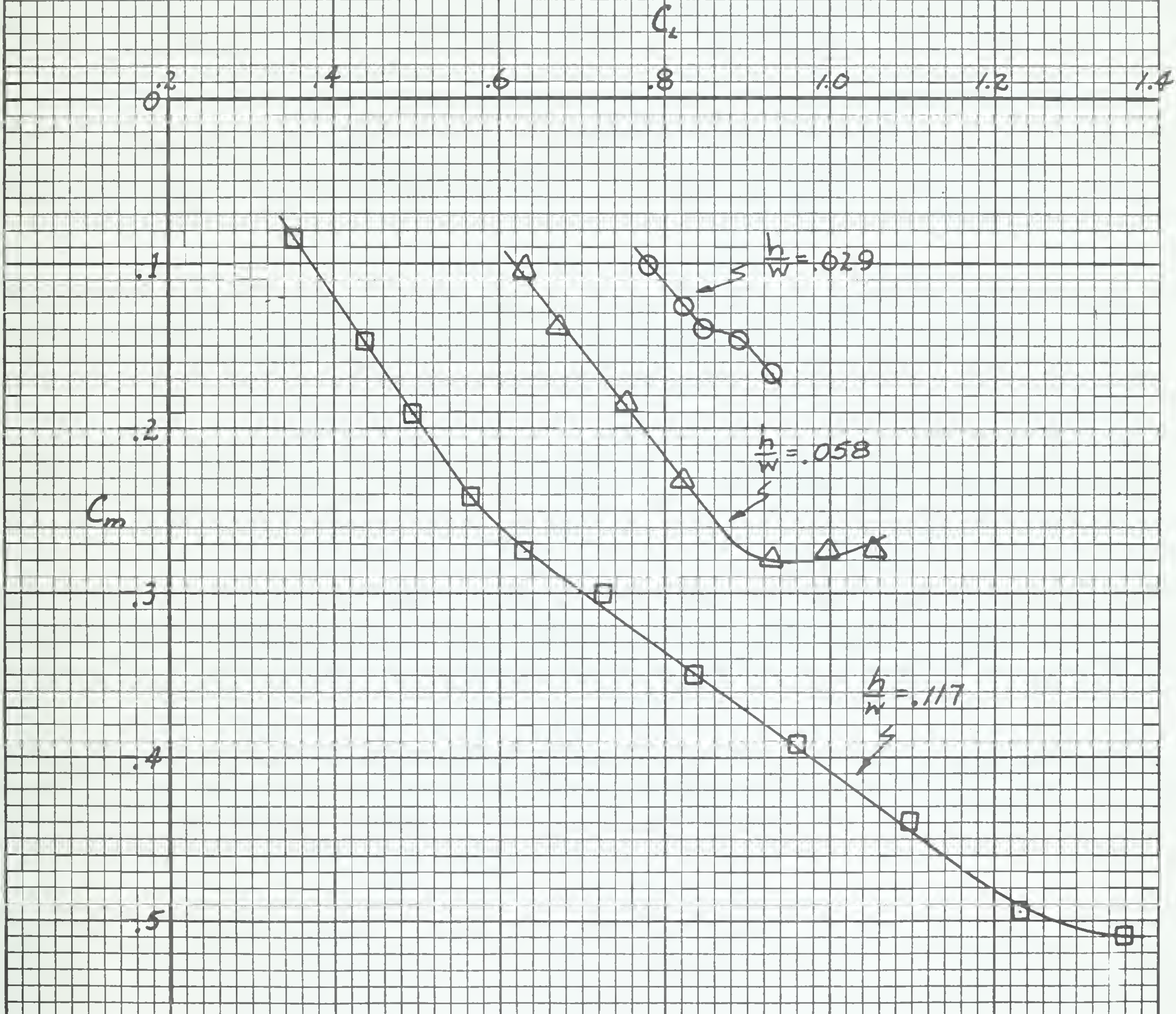


Fig. 26 – Modified C-W Air Car model.
C_m vs α for various model heights.

Fig. 27 - Modified C-W Air Car model.
Static stability for various model heights.



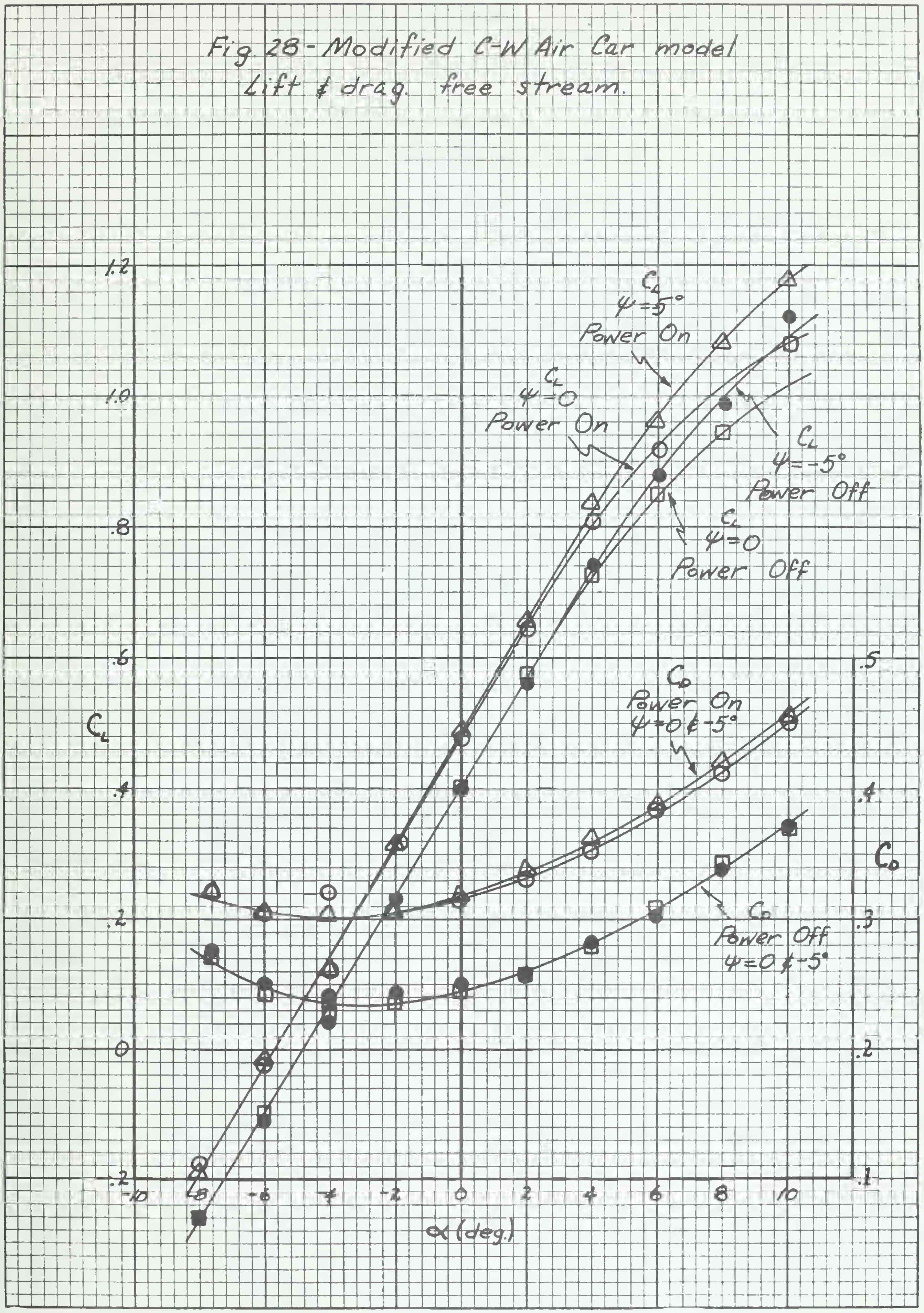


Fig. 28 - Modified C-W Air Car model
Lift ¢ drag. free stream.
C_L
$\psi=5°$
Power On
C_L
$\psi=0$
Power On
C_L
$\psi=-5°$
Power Off
C_L
$\psi=0$
Power Off
C_D
Power On
$\psi=0$ ¢ $-5°$
C_D
Power Off
$\psi=0$ ¢ $-5°$
C_L
C_D
1.2
1.0
.8
.6
.4
.2
0
-.2
.5
.4
.3
.2
.1
-10
-8
-6
-4
-2
0
2
4
6
8
10
α (deg.)

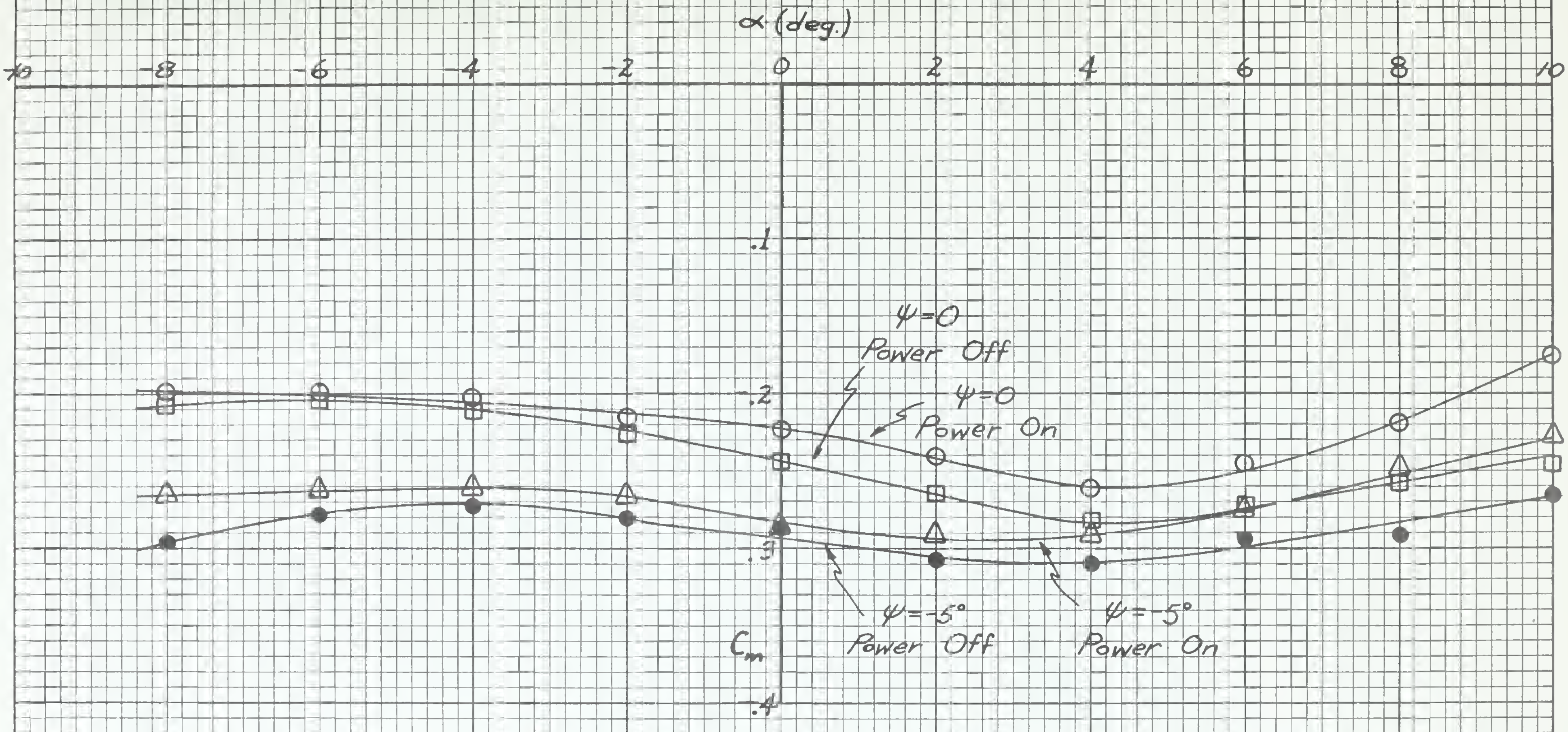


Fig. 29 - Modified C-W Air Car model.
C_m vs α free stream.

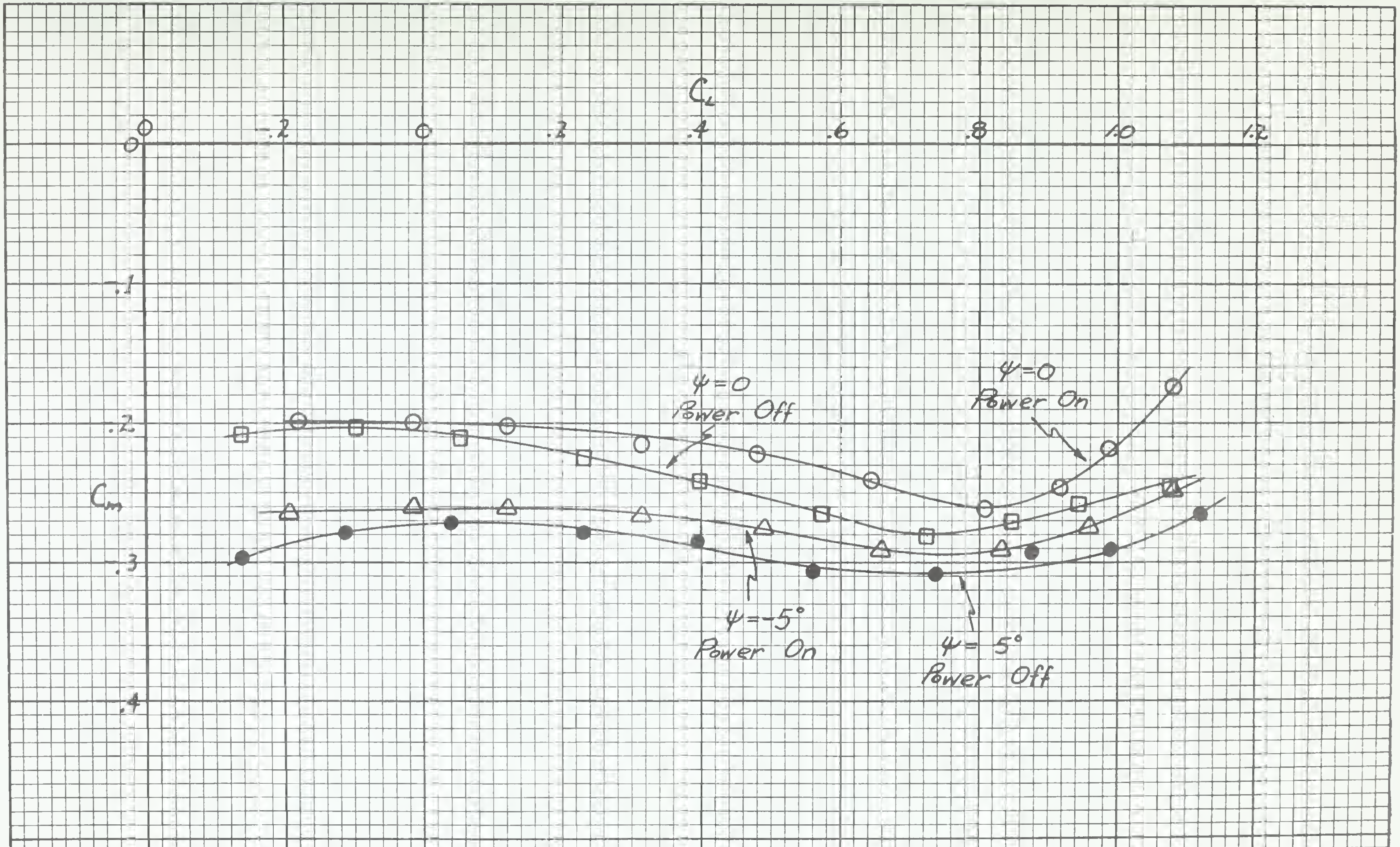


Fig. 30- Modified C-W Air Car model.
Static stability free stream.

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Contract No. DA44-177-TC-833
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Unclassified Report

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